

39. *The SECONDARY ROCKS of SCOTLAND.* Third Paper. *The STRATA of the WESTERN COAST and ISLANDS.* By JOHN W. JUDD, Esq., F.R.S., Sec. G.S., Professor of Geology in the Royal School of Mines. (Read January 23, 1878.)

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I. INTRODUCTION.

THE existence in the Hebrides and adjoining portions of the Western Highlands of more or less isolated patches of limestone, sandstone, and shale, frequently containing fossils, which are interposed between the gneissic and volcanic formations of the district, has been known to geologists for more than a century. During this period many authors, both British and foreign, who have visited the very interesting region in question, have described the peculiar characters presented by some of these curious deposits, their singular relations to the volcanic rocks of the same area, and the remarkable changes which they are in some cases seen to have undergone in proximity to the great igneous masses. In the embittered controversies which so long raged between the Huttonians and Wernerians, too, these deposits were frequently referred to by both parties as lending support to one or other of the rival hypotheses.

That these deposits of fossiliferous rock would have to be classed with the *Secondary* series, in the extended and rather vague sense in which that term was then employed, came to be very generally

recognized about the beginning of the present century; and at a somewhat later date Macculloch pointed out the analogy of the organic remains which he had found in some of these strata with those of the English *Lias*. Beyond these identifications, however, the Scottish geologists seem to have seldom desired to proceed; and, indeed, there was a very general disposition among them to regard any attempts at classifying these strata, and correlating them with the deposits of other districts, rather as idle and useless exercises of ingenuity than as promoting the real progress of geological science.

The teaching of William Smith, that strata may be identified by their organic remains, has never found very ready or hearty acceptance north of the Tweed; and as recently as 1839 we find so able a geologist as Mr. Hay Cunningham giving expression to the views of his countrymen (both those who, like himself, inclined to the Wernerian doctrines and those who accepted the teachings of Hutton) in the following terms:—

“The stratified rocks which we have described as occurring in Eigg are in many other of the Hebrides connected with strata which differ from these, both in mineral and fossil characters. Little examination is required to convince that they form only one series, and that to subdivide them into distinct groups is, since nature has made no separation, a work of little utility. Though we could refer every stratum to its analogue in any other country, say to those of England, nothing would be gained; for as there the several members of the series, though they have distinct names attached to them, belong to one great geognostical group, and present only insignificant mineral and fossil differences, so here the same is evident, and entitles us to consider that there is no necessity to parcel out into minute classes the rocks of a stratified deposit which expresses, when its members are viewed collectively, a system which had been formed uninterruptedly during a well-marked epoch of the world’s ancient history”*.

Passages of similar import abound in the writings of Macculloch and other countrymen of Hay Cunningham; and it is evident to every student of Scottish geology that this neglectful and even contemptuous attitude towards palæontological evidence has done not a little towards retarding the progress of our knowledge of the geological history of the northern portion of our island.

To Murchison belongs the merit of having seen at a very early date the groundless character of the prejudices of his countrymen against the employment of palæontological evidence; he visited the Western Highlands in the years 1826–27, and succeeded in identifying a number of the stratified deposits in the Hebrides with their equivalent English deposits. Unfortunately Murchison’s acquaintance with the Mesozoic formations and their characteristic fossils was at that time very limited, and he in consequence fell into some serious errors in his correlation of the Scottish strata; and, what is still more to be regretted, he altogether failed to recognize the true age

* Memoirs of the Wernerian Society, vol. viii. p. 148, note.

of certain other deposits of great interest which certainly fell under his notice. In spite of these drawbacks, however, Murchison's labours were of the greatest importance and value, in establishing the existence and order of succession of the Liassic and Oolitic strata of the Western Isles.

Up to the year 1870, when I commenced my researches in this area, no Secondary rocks other than those of Jurassic age, had been certainly proved to exist in the Western Isles of Scotland. During the last seven years, however, I have been engaged in working out the relations and order of succession of the various scattered fragments of fossiliferous strata which underlie the enormous masses of Tertiary lavas, and have been gradually led to the following conclusions:—At the base of these sedimentary rocks, intercalated between the Palæozoic schists and the Tertiary lavas, occur strata containing the well-known plants of the Coal-measures, and undoubtedly representing the Carboniferous system—a system hitherto supposed to be wholly absent from the Scottish Highlands. Above these Carboniferous strata are found a great development of the Mesozoic formations, the united thickness of which could have fallen little, if at all, short of a mile. In this vast mass of stratified rocks are included very highly interesting representatives of all the great Secondary systems, with the exception of the Neocomian; we have extensive deposits belonging to the Poikilitic, the Jurassic, and the Cretaceous (the first and last of these being now described for the first time as existing in this area). Further we find that grand unconformities exist in the midst of this series, and indicate the lapse of great periods, which were not epochs of subsidence and of sedimentary deposition in the area which we are describing.

My object in the present paper will be to endeavour to reconstruct, from the scattered and fragmentary records in this area, the history of the succession of geological events during the vast periods of the Mesozoic epoch. I had originally intended to supplement this account of the stratigraphical succession of the deposits with descriptions of such new fossils as have come under my observation during the prosecution of my task; but I now find that this would increase my paper to inordinate proportions, and I have therefore determined to postpone this part of my work; and I do so the more readily, as I find the steadily increasing number of students of palæontological geology in Scotland happily promises to relieve me of this part of my task altogether.

The researches on which this paper is founded have occupied much of my time and thought during the last seven years; and in my last visit to the district, during the summer of 1877, with a view to the final revision of my notes previous to their publication, I had the pleasure of being accompanied and assisted by two students of the Royal School of Mines—Dr. J. Taylor Smith and Mr. R. D. Oldham, the former of whom was with me during a great part of the autumn's work.

II. HISTORY OF PREVIOUS OPINION ON THE SUBJECT.

For the earliest notices of the very interesting rocks which it is the object of the present memoir to describe, we must go back more than a century to the famous work of Pennant, who mentions the occurrence of compressed Ammonites in the rocks of Duntulm in the north of Skye*. At a little later date the Liassic sandstones of the southern coast of Mull are referred to by Mr. Abraham Mills in letters which were read before the Royal Society in the year 1790†.

In Jameson's 'Mineralogy of the Scottish Isles,' published in the year 1800, there are a number of very interesting observations on the Secondary rocks of Mull, Eigg, and Skye, the remarkable relations of which to the volcanic masses of the area were by no means overlooked, though they were too frequently misinterpreted.

Several foreign geologists who have been attracted to the Western Isles of Scotland by the grandeur and interest of the volcanic phenomena displayed in them, have given in their works many valuable notes concerning the associated Secondary strata of the district. Among these we may especially mention M. Faujas de Saint-Fond‡, M. Ami Boué§, M. L. A. Necker-de-Saussure||, and MM. Von Oeynhausen and Von Dechen¶, each of whom has contributed some useful observations on the strata in question.

The geologist who has, however, done far more than any other in seeking for and investigating the relations of the isolated patches of Secondary strata in the Western Isles of Scotland is Dr. John Macculloch. During many years he was indefatigable in his exertions to explore those interesting regions, which imperfect means of communication, with stormy seas and a most trying climate, had combined to render a *terra incognita* to the geologist. The first series of the Transactions of our Society contains several papers bearing striking witness to the earnestness and enthusiasm with which he prosecuted his self-imposed task; and the great work in which he finally embodied the results of his observations** will always remain no less a landmark of the progress of geological knowledge than a monument of the zeal and ability of its author.

As my own task has led me to follow very closely in the footsteps of Macculloch, I think that it is incumbent upon me to speak a word in defence of the fair fame of one to whose previous researches I have been on so many occasions very deeply indebted. In a former volume of this Journal, not only have Macculloch's labours been

* Pennant's 'Tour in Scotland and the Hebrides in 1772,' p. 304. Published in 1774. † Phil. Trans. vol. lxxx. pt. 1, p. 85 (1790).

‡ Voyage en Angleterre, en Écosse et aux îles Hébrides. Paris, 1797. See also his 'Essai de Géologie.' Paris, 1809.

§ Essai géologique sur l'Écosse. Paris.

|| Voyage en Écosse et aux îles Hébrides. Geneva, 1821.

¶ Karsten's Archiv, vol. i. 1829.

** A Description of the Western Islands of Scotland, including the Isle of Man. London, 1819. Two volumes with Atlas.

spoken of in a tone of disparagement, but even his veracity has been called in question. In a subsequent page in this memoir I shall show that the circumstances on which this particular and most serious attack is based have been altogether misunderstood; and I here state my conviction—a conviction arrived at after many years of labour in the same field—that the charges brought against Macculloch by several of his countrymen have no real foundation. Macculloch's rhetorical and inflated style of writing may be objected to as being little suited for scientific description; his unfounded prejudices, his bitterness in controversy, and his want of amiability may be equally regretted; while every one must lament that one so gifted should during the later years of his life have wronged science and his own reputation by taking up a position of sullen isolation, and by refusing to recognize the value or accommodate himself to the requirements of rapidly growing knowledge. But every member of this Society will rejoice if the able geologist who took so prominent a part in its first establishment, and one of whose papers was the first thought worthy of the honour of publication in our Transactions, he who was the first to secure government aid to our science in Britain, and to establish and carry out single-handed a geological survey of the northern part of the kingdom, can be acquitted—as I believe he can be—of the very serious charges which have been brought against him.

Any one who will try to realize the difficulties under which Macculloch laboured—the want of any thing approaching to accurate maps and charts, the difficulties of travel in these stormy seas before they had been comparatively opened up by the introduction of steam-vessels, and the imperfection of geological knowledge at the early date at which his researches were carried on—and then candidly examine the 'Description of the Western Isles,' must, I think, be filled with admiration for the energy and genius of its author. Nor can we forget that in citing the name of Macculloch we furnish some reply—alas, almost the only one possible—to the charges so often brought against our native geologists by foreigners, of contempt for, and actual injury done, to the Petrographical branch of our science.

Macculloch, like Dr. Johnson, has been made the victim of the resentment of a generous but over-sensitive race, which seems to have expected, from one with whom they claimed ties of kindred, unsparing flattery instead of honest criticism. With this cause of quarrel against Macculloch we have, however, nothing to do; suffice it for us if his scientific honour and veracity be vindicated.

The publication of Murchison's two papers on the strata of the Oolitic series in the Hebrides* forms an important epoch in the progress of our knowledge of the rocks treated of in the present

* "On the Coal-field of Brora, Sutherlandshire, and some of the Stratified Deposits in the North of Scotland," Trans. Geol. Soc. 2nd ser. vol. ii. p. 292; and "Supplementary Remarks on the Strata of the Oolitic Series and the Rocks associated with them, in the counties of Sutherland and Ross and in the Hebrides," *ibid.* p. 353.

memoir. Although Murchison appears only to have visited a few of the more conspicuous and accessible of the sections described by Macculloch, yet his application to the beds in question of the principle of identifying them with those of other districts by a comparison of their organic remains led him to some very important and interesting conclusions. Thus, in addition to the recognition of the Liassic beds already made by Macculloch, Murchison was able to define the existence of several members of the Lower Oolites, and to compare their fossils with those of well-known formations in England. His identification of certain Scottish strata with the English Cornbrash and Wealden respectively may be excused on the ground of the imperfection of palæontological knowledge at the time when he wrote; but the same apology can scarcely be made for the confusion into which he fell with regard to the Middle Lias and Lower Oolite, or for his failure to recognize the true age of certain other fossiliferous rocks that came under his notice. Short, however, and somewhat superficial as were Murchison's researches in the district, he deserves to rank, on account of the excellence of the methods he introduced into the study of the district, as second only to Macculloch himself among the investigators of Hebridean geology.

With the exception of the examination of the Secondary strata in the Island of Eigg by Hay Cunningham*, Hugh Miller†, and Professors Geikie and Young‡, the subsequent work which has been done in the elucidation of the Jurassic rocks of the Western Highlands has consisted in the re-examination by more competent palæontologists of the sections to which Murchison had called the attention of geologists by his important discoveries.

In 1851 Prof. Edward Forbes visited Loch Staffin and showed by the fossils which he obtained that the freshwater beds there could not be of Wealden age as suggested by Murchison§.

In 1858 Dr. Thomas Wright, by the study of a series of fossils collected by Professor Geikie in the district of Strath in Skye, was enabled to speak with much more exactness as to the particular subdivisions of the Lower and Middle Lias which are there exhibited||.

In 1862, Messrs. Davidson and Etheridge, in like manner, examined a series of fossils collected by Captain E. J. Bedford, R.N., from the Middle Lias at Carsaig Bay, in the Island of Mull, during the survey of the coasts of that district for the Admiralty¶.

Still more recently Professor Tate has studied carefully the series of fossils collected during several years by the indefatigable geologist Dr. Bryce, who has so recently sacrificed his life in the prosecution of his favourite studies**. As the collections submitted to Professor Tate were very carefully made, and he had, moreover, the opportunity of studying the sections themselves, his identifications of the

* Memoirs of the Wernerian Society, vol. viii.

† See his 'Cruise of the 'Betsy,' and other works, in which many valuable observations on this island are recorded.

‡ Quart. Journ. Geol. Soc. vol. xxvii. p. 288.

§ *Ibid.* vol. vii. p. 104.

|| *Ibid.* vol. xiv. p. 24.

¶ The Geologist, vol. v. p. 443.

** Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 317.

several geological horizons are particularly valuable and satisfactory—the more so from his well-known extensive knowledge of Jurassic palæontology.

It may be right to mention that the discovery by myself of Cretaceous and Carboniferous strata in the Western Islands has already been announced, though without any details being given—the first in a letter to Sir Charles Lyell, which was read at the meeting of the British Association in 1872 by Professor Hughes*, the latter in a letter to the 'Geological Magazine'†; while the general nature of these recent discoveries and their bearing on the geology of the Highlands have been discussed by the Duke of Argyll, in his paper read at the meeting of the British Association at Glasgow in 1876‡.

III. DISTRIBUTION AND PHYSICAL RELATIONS OF THE SECONDARY STRATA OF THE WESTERN HIGHLANDS.

In the last published part of this memoir I endeavoured to give such a sketch of the relations of the Tertiary volcanic rocks to the strata of Mesozoic age as would enable the reader to realize those peculiar accidents by which the preservation of the numerous isolated fragments of the latter have been determined. I showed that at the commencement of the Tertiary epoch considerable areas in the north of Scotland must have been covered by deposits of Secondary age, attaining in places to a very great thickness, and that during Eocene and Miocene times there had occurred, in the district of the Western Highlands, a series of volcanic outbursts on the very grandest scale; that these tremendous exhibitions of igneous violence were succeeded, probably during the Pliocene period, by numerous smaller and sporadic eruptions; and that, as the consequence of this prolonged volcanic action, portions of the Secondary strata were in some cases buried under enormous thicknesses of slowly accumulated lava-sheets, while other portions were caught and entangled between the intrusive sheets proceeding from the great centres of igneous activity. In some instances, as I then pointed out, the Secondary rocks were subjected to metamorphic action, through their contact with the intrusive plutonic masses, and occasionally the metamorphism thus produced was of the most extreme character: in other cases the Secondary strata were broken up by the explosive action of the volcano, so that we now find only their fragmentary relics imbedded in the ejected agglomerates constituting portions of the old cones of eruption; and it is from these fragments alone that the geologist is enabled to form a judgment concerning the nature and fossil contents of the rocks through which the volcanic agencies forced vents. But in every case it is in consequence of the extensive denudation to which, as we have shown, the volcanic rocks of the Hebrides have been subjected, during comparatively recent times, that the

* Rep. Brit. Assoc. (1872), Transactions of Sections, p. 115.

† Vol. i. new series, p. 573.

‡ Rep. Brit. Assoc. (1876), Transactions of Sections, p. 83.

isolated fragments of the Secondary strata are now revealed to us; and, except where protected by the harder and less perishable volcanic rocks—either burying them under enormously thick accumulations of lava or entangling them between igneous sheets—almost every vestige of the Mesozoic strata has been removed by the denuding forces. Nevertheless, wherever portions of the great basaltic plateaux have escaped being swept away by the denuding forces, as in the islands of Muck and Eigg, there masses of the Secondary strata are found cropping out from beneath them; while around the igneous centre of Ardnamurchan, and perhaps also that of Rum, the same strata, metamorphosed indeed almost beyond recognition, are found entangled between igneous sheets and intersected by a plexus of dykes.

I cannot here refrain from citing a vivid illustration of the manner in which the preservation of these curiously isolated fragments of the Mesozoic deposits has been effected, which was suggested to me by the late Sir Henry James a few years ago, when I had an opportunity of conversing with him upon the subject. He compared the fragments of such strata, which have escaped removal by denudation, to the little bits of paper that would escape being washed away if a newspaper with a number of heavy stones on it were laid in the bed of a running stream.

The isolated patches of Secondary strata are now found widely scattered over an area measuring 120 miles in length from north to south, and 50 miles in breadth from east to west. Within these limits, however, such patches occur only where those peculiar conditions have prevailed which, as we have shown, have determined the preservation of these fragmentary relics—namely, in proximity to the great Tertiary volcanos of Skye, Rum, Ardnamurchan, and Mull. Thus the whole northern part of the island of Skye consists of a plateau of basaltic lavas poured out from the volcanic centre of the Cuillin Hills; all round the edges of this great basaltic plateau the Secondary rocks, which they have overwhelmed, can be traced here and there in cliff-sections; and at a few points in the interior, where valleys have been cut deeply into the plateau, inliers of the same Mesozoic deposits make their appearance. From the careful study of the phenomena presented at these various points, it becomes clear that the denuded surfaces of these Secondary rocks formed the terrestrial areas on which the lavas were poured out. In Raasay the same relations are exhibited in an equally striking manner, the Secondary rocks making their appearance all round the shores of the island, under the covering of Tertiary lavas which forms its higher portions. Even where the most minute isolated patches of the Tertiary lavas occur, as at Strathaird and Ru-Geur in the southern part of Skye, the Secondary rocks are found to be preserved beneath them. Still more strikingly is this found to be the case in Mull, where patches of Secondary strata can be traced at short intervals all round the shores of the island and in the adjoining district of Morvern, in such a manner as to lead to the irresistible conviction that the great volcano of that district was opened in the

first instance in the midst of strata of Secondary age, and that its lavas almost everywhere rest on deposits of the same age. The manner in which the central subsidence, which has been so very marked in the case of the volcano of Mull, has operated in the more perfect preservation of its lava plateaux from denudation than is the case in the contemporaneous volcanos we have described on a former occasion; and the underlying Mesozoic rocks have, of course, also been saved from destruction with their protecting capping of lavas, though at many points they have been by the same action depressed beneath the sea-level and thus withdrawn from the ken of the geologist.

The volcanos of Rum and Ardnamurchan were of smaller dimensions than those of Skye and Mull, and they have, in consequence, suffered more from denudation. On the other hand, wherever the plateaux of protecting lavas have been removed, as is the case in the greater part of the district of Sleat in Skye, and in the northern part of Rum, there all traces of the Secondary rocks have disappeared also. It is when viewed in this relation that such minute outliers of the volcanic rocks, preserving between themselves and the underlying gneissic rocks slices of Secondary strata, are of such especial interest. Such examples occur at Ru-Geur, in Skye, and in the remarkable mountains of Morvern, to be described hereafter.

From an examination of all the circumstances of the case, it appears to me to be impossible to avoid the conviction that these patches of Secondary strata, although now so minute in dimensions and isolated in position, once formed portions of a great series of connected deposits which covered the greater part of the vast area we have indicated, and attained in places a thickness of from 4000 to 5000 feet.

But an attentive consideration of the facts of the case will, I believe, compel us to go a step further in the same direction. We find, 80 miles to the southward of the exposures of the Secondary strata in Mull, and exactly at the point where there exists a recurrence of those conditions which have determined the preservation of the Mesozoic rocks in the Western Isles, an almost precise repetition of the familiar phenomena presented by the Scotch deposits in question. In the island of Rathlin and the north-east of Ireland we meet—just as in the Hebrides and Western Highlands—with a series of Carboniferous, Poikilitic, Jurassic, and Cretaceous strata interposed between the Palæozoic schists and the Tertiary basalts. And, as we shall show hereafter, the relations between the Scotch and Irish Secondary deposits are of the most intimate and unmistakable character. Can we then avoid the conclusion that the absence of traces of the Secondary strata in the intervening area is not to be accounted for by the inference that they were never deposited in that district, but that it is to be set down entirely to the absence of those peculiar conditions by which alone, as we have seen, any portions of the strata of that age could have escaped destruction during the great ordeal of denudation to which the district has been subjected?

Nor do I think that it will be possible to pause here. For, as has been shown in the first part of this memoir, there are various deposits of Mesozoic age in the counties of Sutherland, Ross, and Elgin, the nearest of which lies 100 miles to the north-east of the most northern patch of Secondary strata in the Western Isles; and these fragments of Secondary strata in the Eastern Highlands have, as was there pointed out, escaped destruction by denudation only in consequence of being let down many hundreds, or even thousands, of feet below their original positions, and thus coming to be preserved in the very heart of the much harder Palæozoic masses. If, on the other hand, we proceed from the patches of Secondary strata in the Hebrides in a south-easterly direction, we find in Cumberland and on the borders of Cheshire and Shropshire fragments of Liassic deposits faulted down into the midst of the older rocks; and these form a connecting link with wide-spreading tracts of the same strata in the south-eastern part of England.

In the face of these facts, I believe that it is impossible to avoid the conclusion that the whole of the north and north-western portions of the British archipelago—now sculptured by denudation into a rugged mountain-land—were, like the south and south-eastern parts of the same islands, to a great extent, if not completely, covered by sedimentary deposits, ranging in age from the Carboniferous to the Cretaceous inclusive; and that, as a consequence, we must refer the production of the striking and very characteristic features of those Highland districts to the last great epoch of the earth's history—the Tertiary—and very largely, indeed, to the latest portion of that epoch, namely the Pliocene.

It may be objected to this view concerning the recent date, geologically speaking, of the origin of the existing surface-features of the Scottish Highlands, that it is impossible to conceive of such a vast amount of marine planing down and of subaërial gouging of a series of rocks of the hardest character having been accomplished within what we are sometimes tempted to regard as comparatively short geological periods. But in reply to such an objection, I would point to the enormous effects that have clearly been produced since Miocene times in the Western Isles of Scotland, in the destruction of the old volcanic cones of that area, and more especially in the sculpturing of mountain-forms out of their intensely hard cores of gabbro and hypersthenite; to the work that has been accomplished in the same area, probably since Pliocene times, as borne witness to by the Scur of Eigg and the rocks of Beinn Shiant in Ardnamurchan; to the fact, which I have described in a former paper, that since the period of the Upper Jurassic, thousands of feet of the Middle Old Red Sandstone or Caithness flagstones must have been removed from the surface of Sutherland, as is clearly demonstrated by the preservation of a portion of those beds by the singular double fault already described*. But most strikingly of all is this fact of enormous denudation of the Scottish Highlands during very recent geological periods demonstrated by the occurrence of numerous post-Miocene faults, having

* Quart. Journ. Geol. Soc. vol. xxix. pp. 132-134.

downthrows of various amount, up to nearly 2000 feet, the effect of which upon the surface has been entirely masked by post-Miocene denudation.

He who wishes to obtain some faint idea of the vastness of the periods of time represented by our great geological systems, cannot do better than go to the Western Highlands. After taking careful note how little has been accomplished by meteoric agencies since the Glacial epoch in obliterating its characteristic markings, let him study the enormous changes which have clearly resulted from the action of the same forces operating during and subsequently to the Pliocene period.

That during all the geological periods, from the Carboniferous to the Cretaceous inclusive, a very large part of the Highland districts was submerged, and formed areas of deposition, I think it is impossible to doubt; but that some portions of that Highland region did, during those long periods, exist more or less continuously as islands, we shall see in the sequel that there are good grounds for believing. Yet so uniformly similar is the succession of life-forms during the Mesozoic deposits, as exposed in Central Germany, in Northern France, in England, Scotland, and Ireland respectively, that it seems to me impossible to doubt that the Jurassic and Cretaceous deposits of all those areas were accumulated in the same sea—one in which the diffusion of the forms of life was not impeded by the existence of any great continuous barrier of land.

So far as I have been able to ascertain, there is only one exception to the statement that has been made that the Secondary strata of the Western Highlands owe their preservation to the agency of the Tertiary volcanic outbursts. This single exception occurs in the case of the Poikilitic strata of Gruinard Bay—where the soft unmetamorphosed strata in question have escaped total removal by denudation, in consequence of the action of the same causes as have, on the eastern coast of Scotland, effected the preservation of the Secondary strata. The beds of Gruinard Bay constitute the most northern exposure of Secondary rocks on the west coast of Scotland; they occur at a considerable distance from any of the great Tertiary volcanic centres; they are not traversed by the dykes, nor do they exhibit any evidence of having been ever covered by the lava-currents of that period. The beds in question, indeed, appear to owe their escape from destruction by denuding forces solely to the fact that they have been let down amidst the hard metamorphic rocks of the district by a great trough-fault, as shown in the following section (fig. 1), which I have constructed from data obtained by Dr. Taylor Smith and myself, and laid down on the excellent Admiralty chart of that part of the coast.

In all other cases of the preservation of patches of Secondary strata on the west coast of Scotland, the presence of Tertiary volcanic masses above or between them has evidently played a very important part in bringing about the result. In not a few instances, however, great movements and dislocations of the strata themselves have occurred, either before, during, or subsequently to those volcanic outbursts; and these, it is clear, have contributed, sometimes in a

Fig. 1.—Section illustrating the relations of the Poikilitic Strata of Grunard Bay to the underlying Torridon Sandstone.
(Length of the Section about 3 miles.)

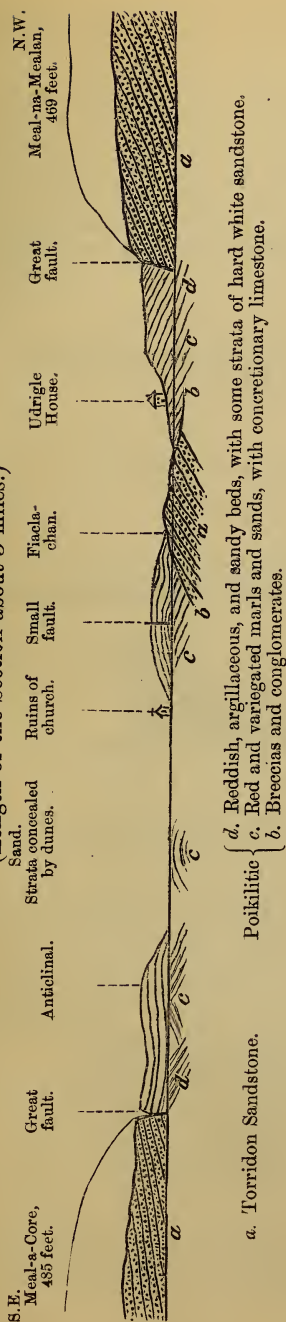
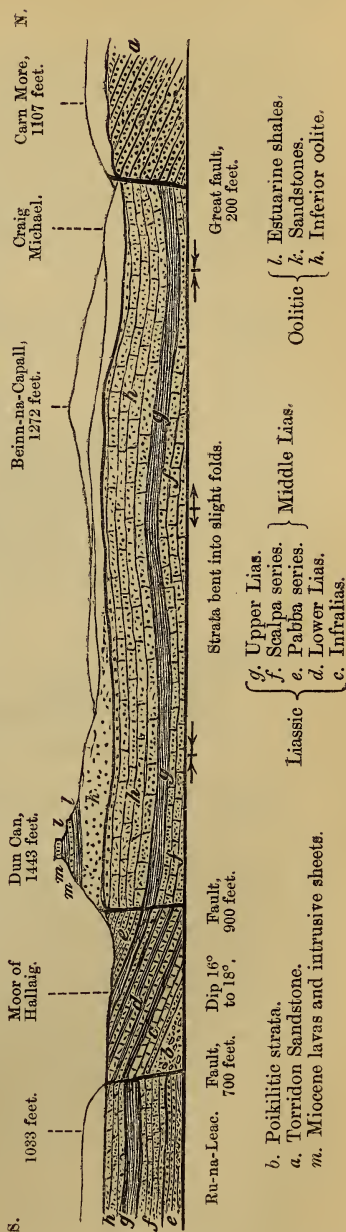


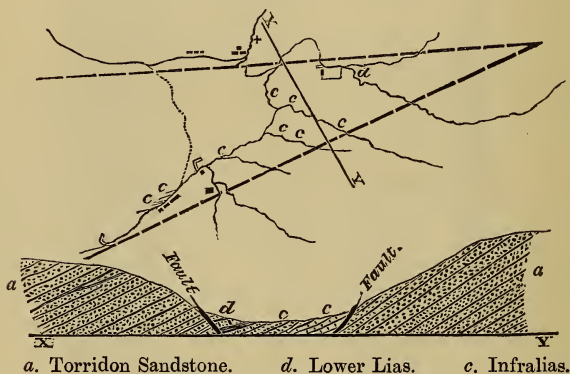
Fig. 2.—Great Cliff-section on the East Side of the Island of Raasay. (Length of the Section about 5 miles.)



very important degree, to the preservation of the fragments of Mesozoic rocks.

Thus in the case of the remarkable mass of Mesozoic rocks at Applecross, though it is highly probable (alike from its proximity to the Skye volcano and the fact of its being traversed by numerous basaltic sheets and dykes) that this patch of strata was originally buried under an accumulation of lava-sheets, which have since been entirely removed by denudation, yet it is manifest that the great faults which have clearly let down these strata many hundreds and perhaps thousands of feet below their original level into the heart of the mountains of Torridon Sandstone have had much to do with their preservation (fig. 3).

Fig. 3.—*Plan and Section to illustrate the relation of the patch of Liassic Strata at Applecross.*



The broken lines in the plan indicate the positions of the great faults.
The line X Y shows the line of the section represented below the plan.

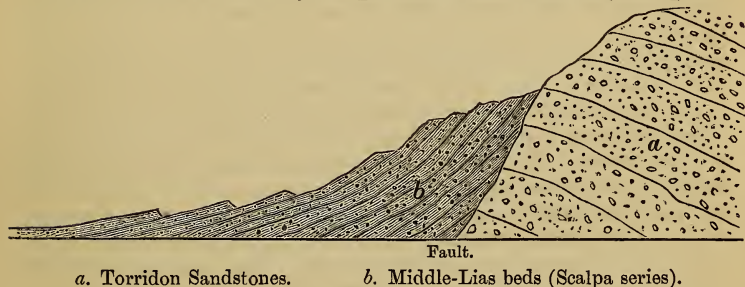
The action of great faults, in combination with a covering of sheets of lava, in effecting the preservation of masses of Secondary strata is very strikingly exhibited in the grandest of all the sections of Mesozoic rocks in the Western Highlands, that of the eastern side of the island of Raasay, lying opposite to and only a few miles distant from Applecross. This section is illustrated by the accompanying diagram (fig. 2, p. 671), in which the amount of disturbance to which the strata have been subjected is strikingly apparent.

The relations of the strata in the island of Scalpa, which I had the opportunity of studying with one of the students of the School of Mines, Mr. A. Grant, at the time resident in the island, are quite similar to those just described in the island of Raasay, the Middle-Lias beds being thrown against the Torridon sandstone by a great fault as shown in fig. 4.

The most striking example, however, that can be adduced of the action of faults in contributing to the preservation of the Secondary

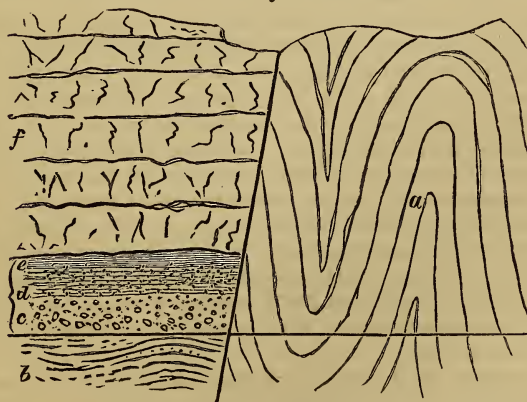
strata of the Western Islands from destruction by denuding forces is that afforded by the magnificent section of the Innimore of Ardtornish. Here we find a series of lava-sheets poured from the great volcanos of Mull and Ardnamurchan during the Miocene period (the greatly denuded masses of which retain a thickness of over 1200 feet) lying upon a series of strata ranging in age from the Carboniferous to the Upper Chalk. There Secondary and Tertiary strata have been cut across by a fault, probably having a throw of nearly 2000 feet, by which they have been brought into apposition with vast mountain-masses of gneiss, probably of Cambrian and Silurian age (see fig. 5).

Fig. 4.—*Junction of Torridon Sandstone and Middle-Lias Strata, as seen a little to the West of Scalpa House, in the Island of Scalpa.*



The dip of the Middle-Lias strata is found to increase gradually, as we approach the line of fault, from 3° up to 35° or more.

Fig. 5.—*Section exposed at the Innimore of Ardtornish, on the Sound of Mull.*



{ e. Marls.
 d. Sandstones.
 c. Conglomerates. } Poikilitic.

a. Gneiss and schist (Palæozoic).

At a distance of only a few miles another fault of smaller dimensions crosses the outlying mass of Beinn-y-Hattan.

Apart, however, from the great dislocations, the effects of which, as we have seen, are so clearly manifest in the Western Highlands, it is evident that, wherever preserved from denudation, the basaltic plateaux of Miocene lavas, with their foundations of Secondary strata, have owed their survival in a very great degree to powerful earth-movements which have taken place. In the case of the Skye volcano only a sector of about 50 degrees has escaped removal by denudation out of the vast circular area of lavas which doubtless originally surrounded it on all sides. The isolated masses of Secondary rocks, capped by lava, in Dun Can, Strathaird, and Ru-Geur, with the plexus of dykes and sheets that intersect all the older rock-masses of Strath and Sleat, bear witness in the strongest possible manner to the fact that the volcanic action extended equally on all sides from the Cuilin and Red Mountains of Skye. As was well recognized, too, by Macculloch, Murchison, and Forbes, as well as by later authors, the great lava-plateau forming all the northern part of the island of Skye exhibits in itself very striking evidences of the irregularities of the great earth-movements which have taken place in the district. Thus, while on the eastern coast of Trotternish the Secondary rocks are found in the cliff-sections up to 1000 feet above the sea-level, on the western coast they only just make their appearance at a few points at that level, and for the most part, indeed, are concealed altogether by the Tertiary lavas. The same inclined position of the lavas of the basaltic plateaux is quite as strikingly seen in Raasay as in Skye. Of minor flexures and fractures which have occurred in both districts since the ejection of the Tertiary volcanic masses, the number is almost infinite, and the striking effect produced by them is sufficiently patent to every one who studies those wonderful coast-sections.

In Mull the plateaux of basaltic lava have apparently suffered less from denudation than have those of Skye; and this is the result of that central subsidence which, as I have shown in a former paper, has produced such marked effects in the case of that volcano; but even in Mull, that great breach in the lava-plateaux which constitutes the Sound of Mull, their interruption by numerous sea-lochs, and their total removal on the south and east sides of the igneous centre speak very impressively indeed of the enormous amount of waste of the Tertiary volcanic rocks and of the subjacent Secondary strata by denudation. The same conclusion is very strikingly confirmed by an examination of the isolated patches of the basaltic plateaux forming the islands of Staffa and the Treshnish group, all of which have doubtless been separated from Mull by post-Miocene denudation aided by earth-movements.

Most strongly do the causes of the preservation of these strata make themselves felt in the case of that great line of fault which forms the north-western boundary of the Mull plateaux, and in that singular series of outliers of basaltic rocks forming the summits of mountain-peaks in Morvern, and reserving beneath them those re-

markable patches of Secondary strata, on the singular isolation of which I have already spoken; and the diagram section, Pl. XXXI. fig. 2, will sufficiently serve to illustrate the peculiar manner in which the patches of Secondary strata are exhibited in these remarkable outliers.

Around the smaller volcanos of Rum and Ardnamurchan the destruction of the basaltic plateaux has been carried still further, and only a few fragments in the island of Rum, with those of Eigg and Muck and that in Ardnamurchan, remain to tell of their former vast extent and thickness. In the cases of the island of Eigg and of the peninsula of Ardnamurchan it is clear that this work of destruction by denudation would have been carried much further but for the fact of the protection to the Miocene basalts afforded by the solid masses of newer lavas erupted in Pliocene times—those, namely, which form the lofty ridge of the Scur in the former case and the mountain-pass of Beinn Shiant in the latter.

Now the volcanic action which took place during the Tertiary epoch has operated in three different ways in effecting the preservation of relics of the Secondary strata in the Western Highlands.

First, by burying these strata under deposits of lava, the successive streams of which were in some cases piled upon one another to the depth of 2000 feet. By this means the destructive effects of denuding forces on the soft Mesozoic deposits has been arrested during the enormous periods required for the removal of these vast masses of lava.

Secondly, by entangling portions of the Secondary strata between sheets of igneous matter, intruded in a fluid condition into their midst, usually in planes coinciding approximately with those of the bedding of the sedimentary masses. As these intrusive sheets usually consist of rocks of highly crystalline character and intense hardness, they frequently display most remarkable powers of resistance to the denuding forces; and the patches of Secondary rock enclosed between them—which have often themselves been rendered less susceptible to disintegrating action through contact metamorphism—are preserved with them.

Thirdly, by enclosing fragments of the Secondary rocks after they were blown from eruptive vents in the piles of agglomerate and tuff constituting parts of the ancient Tertiary volcanic cones.

The frequency with which the traces of Secondary strata are found appearing from underneath the lava-cliffs of the great basaltic plateaux of the Hebrides is very remarkable. As in many of these instances, however, the beds in question are almost wholly concealed by taluses, while in others they are exposed to view only at dead low-water, and in some cases they must be examined during favourable concurrences of spring-tides with certain winds, their study is attended with great difficulties; but it is almost certain that, were we able to reach the base of the series of lavas at other points, we should find many more exposures of the Secondary strata. In short, it is clear that those great movements of subsidence which, as we have seen, have operated so powerfully in the Western Isles, have

had the effect of placing many of the Secondary rocks far below the sea-level, and thus hopelessly out of reach of at least the present race of geologists.

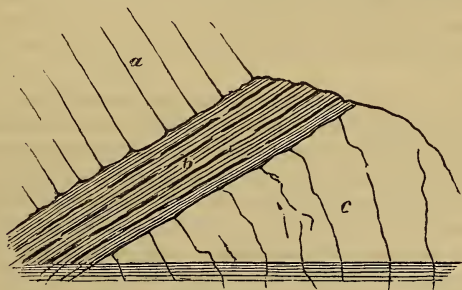
The examples of the relations of the Secondary rocks of the Hebrides to the superincumbent lava-masses which we have already given will sufficiently illustrate the first of the three methods by which the Mesozoic relics have been preserved. Of the second case, that in which masses of the Secondary rocks have survived to the present time through being included between intrusive sheets of igneous rock, we have also many striking examples. On the east coast of the peninsula of Trotternish, in Skye, as was so well shown by Macculloch, the sheets of dolerite are found running along the planes of bedding of the Secondary strata for miles with the greatest regularity; so strikingly is this the case, indeed, that they might easily be mistaken for contemporaneous lavas, but for the fact that they occasionally cross the lines of stratification or send off dykes and veins into the enclosing beds, which exhibit signs of metamorphic action as well above as below the intrusive sheets. Between Loch Staffin and the Kilt rock, on that part of the coast of Skye, an intrusive sheet of dolerite, which is about 100 feet in thickness and remarkably columnar in character, is seen forced between and capping a series of interesting Secondary rocks, the preservation of which is clearly due to its presence and power of resisting denudation. At points a little further to the south, on the coast of Trotternish, as many as eight or nine intrusive sheets of dolerite may be traced traversing the Mesozoic strata in parallel planes. Occasionally, indeed, as is well seen near the north point of the island of Eigg, the intrusive sheets are so numerous and so close together that the included beds of Secondary rock become quite insignificant and subordinate to the igneous masses which have been thrust between and now enclose them.

But the most striking example of the kind which we are able to adduce is unquestionably that of the Shiant Isles, where fragments of the Secondary strata are seen to be entangled between two intrusive sheets of truly stupendous proportions. The uppermost of these is over 500 feet in thickness, and consists of excessively coarse dolerite passing into augitic gabbro, the whole having a grandly columnar structure, the columns having a diameter of 5 or 6 feet. Of the lower intrusive mass only the upper part is seen, and it does not exhibit the columnar structure in any thing like perfection. It is impossible for the geologist to look upon the grand cliff of the island of Garaveilan, with its façade of columns resting on a base of altered shale and sandstone and rising to a height of more than 50 feet—the whole constituting an object far surpassing Staffa, if not in regularity and grace, at all events in grandeur—without reflecting on the enormous amount of dislocation and crumpling of the surrounding rock-masses which must have been produced when this tremendous wedge of igneous material was forced into their midst. The igneous masses of the Shiant Isles were not improbably connected with a centre of volcanic activity in Tertiary times, of which every trace has been since

removed by denudation, except these three small islets lying midway between the northern extremity of Skye and the Lewis.

The general relations of the volcanic rocks to the Mesozoic strata in the Shiant islands are exhibited in the accompanying section (fig. 6).

Fig. 6.—*Secondary Strata of Inferior-Oolite age entangled between two intrusive sheets of Dolerite, Garaveilan, Shiant Isles.*



- a. Coarse dolerite, forming massive columns.
- b. Inferior-Oolite shales and sandstones greatly altered.
- c. Dolerite imperfectly columnar.

Of the third method by which relics of the Mesozoic period have sometimes been preserved—namely, the inclusion in volcanic agglomerates of fragments of Secondary rock torn from the sides of the vents and brought to the surface by explosive action—we have many examples, especially in the case of the island of Mull, some of which I have alluded to in a former paper. These fragments not unfrequently contain fossils, and thus, like the similarly ejected masses found in Vesuvius and other recent volcanos, furnish clear evidence of the nature of the age and character of the rocks through which the igneous vents have been opened and on which the volcanic cones have been piled up.

From this description of the various conditions under which the patches of Secondary strata have been preserved for our study, it will be clear that the work of investigating their age and their relations to one another, though full of promise, is, nevertheless, attended with very considerable difficulty.

The Secondary strata of the west coast of Scotland are found lying sometimes upon the Torridon Sandstone, at others upon the great gneissic series of the Highlands—now usually referred to the Silurian. Occasionally, as on the south side of the island of Mull, they may be observed resting directly upon the volcanic rocks and conglomerate beds of the Old Red Sandstone period; while in one very interesting case, that of the Innimore of Ardtornish referred to above, I have detected them reposing on strata of Carboniferous age. It is clear, from the unconformable relations of these Mesozoic strata to all the older series of rocks, that disturbances and denudation on the most enormous scale must have preceded their deposition.

Equally certain is it that very considerable subterranean movements and a vast amount of denuding action must have taken place in the area in question during the Mesozoic period itself. This is proved by the irregularities in thickness and the variations in the development of the different members of the Secondary series, and still more by the striking unconformities between certain of them. Thus, as we shall point out more fully hereafter, the Upper Cretaceous strata overlap all the older rocks, being seen to rest on the Middle Lias at Carsaig, the Lower Lias at Loch Aline, the Poikilitic at the Innimore of Ardtornish, and the Older Palæozoic at Gribun.

Except in a very few instances, such as those of Strath, Applecross, and Ardnamurchan, the Secondary rocks do not constitute any conspicuous areas capable of being represented upon geological maps; in the cases cited it is sufficiently manifest, too, that they are now only exposed at the surface, in consequence of the removal of superincumbent lava-masses by denudation. The determination of the relations of these isolated fragments of strata to one another by mapping their lines of outcrop is therefore altogether out of the question in most cases; and in the few in which it is at all practicable the amount of dislocation and igneous intrusion to which the strata have been subjected renders the task one of much difficulty and, at best, very considerable uncertainty.

Continuous sections of these rocks are also rare, and where they do exist, as on the east coast of Skye, are usually much interrupted, complicated, and obscured by the intrusion of sheets and dykes of igneous rocks among the strata. In the magnificent precipices of the east coast of Raasay it is true that we have a section of over 1000 feet in depth extending for a distance of several miles, one which is perhaps without a parallel for its magnitude and variety in the British Islands; but even here there is, unfortunately, a very serious drawback to the satisfaction felt by the geologist who studies this section; for its very magnitude militates against its value, since a very large portion of it is utterly inaccessible, and those parts which can be reached are much obscured by taluses. Even the smaller and more accessible sections of the Secondary rocks exposed beneath the basaltic cliffs of the Western Isles are also often, to a very great extent, covered and concealed by fallen masses of the harder igneous masses which have tumbled from above; and in such cases the best exhibition of the beds is often to be found in the reefs exposed along the shore at low water.

In addition to these hindrances to his study the geologist too frequently finds that the patches of Secondary rocks, even when reached, are capable of affording him very little information. Wherever, for example, these masses of Secondary rocks happen to be in close proximity to one or other of the great volcanic centres, as in Ardnamurchan and along the greater part of the south coast of Mull, the strata have been metamorphosed almost beyond recognition; they are in such cases found to have assumed a more or less crystalline character, and

their fossils have been often to a great extent and sometimes completely obliterated. It is, indeed, only at considerable distances from the centres of igneous activity that the geologist has the smallest chance of finding these sedimentary masses in a sufficiently unaltered condition to supply him with useful records of the periods during which they were deposited; and even in some cases where they are at a sufficient distance from the great volcanic centres to have escaped in the first instance from metamorphic action, subsequent smaller outbursts, which have taken place in close proximity to them, may have produced injurious effects on their fossil contents, as is well seen beneath Beinn Shiant.

Among the difficulties caused by the complication of stratified deposits with intrusive sheets we may mention that of determining their exact thickness, the task being in some cases, indeed, as in the north of Eigg and in Trotternish, rendered absolutely hopeless in consequence of the number and capricious behaviour of the intrusive masses lying in their midst.

Of the wonderful changes at times effected in the character of the sedimentary strata, of the complex intervening of bedded and intrusive masses, such as is seen in Strathaird, Ardnamurchan, Rum, and Mull—where the bulk of the intrusive sheets and dykes taken collectively sometimes far exceeds that of the older stratified masses among which they have been forced—it is impossible to convey any adequate idea to those who have not had an opportunity of visiting the district. Macculloch's drawings of the dykes of Strathaird* and of the wonderful section of Stronbeg in Ardnamurchan† may perhaps give some faint idea of the strangeness, complexity, and interest of the phenomena in question.

But in spite of the numerous difficulties, the serious obstacles, and the trying disappointments which the investigator of the Secondary strata of the Western Isles must be prepared to encounter in his task of detecting and studying these isolated patches of fossiliferous rock, of reasoning concerning their relations, and of combining these scattered relics of a long series of epochs in the world's past history, he finds most ample compensation in the absorbing interest of the subject; nor will he begrudge any labour or pains when he reflects upon the importance of these singularly preserved fragments of geological evidence in enabling us to reconstruct the physical features of this portion of the globe during long past periods, and to unravel the complicated series of changes which the district now forming the Highlands of Scotland has undergone in the past. I cannot, indeed, conceive of a work more delightful to any one who has felt the least touch of the enthusiasm of research than that of seeking for and piecing together these torn, blotted, and almost utterly defaced pages of the geological record, and weaving from them a connected story.

* 'Western Isles of Scotland.' Atlas, pl. xiv. fig. 5, and pl. xvi. fig. 1.

† *Ibid.* pl. xxxiii. fig. 1.

IV. GENERAL CHARACTERS AND SUCCESSION OF THE SECONDARY STRATA OF THE WESTERN HIGHLANDS.

In describing the Mesozoic rocks of the Eastern Highlands, we had occasion to refer again and again to the frequency with which deposits of marine origin alternate with others that exhibit clear evidence of having been accumulated under *estuarine* conditions. As we have already shown, this alternation of marine and estuarine strata constitutes the most salient and striking feature throughout the whole series of Secondary formations in Sutherland and on the east coast; and in the equivalent deposits on the western coasts and islands, the same phenomenon, if exhibited in a less marked degree, is nevertheless sufficiently common to impart to these strata characters by which they are strikingly distinguished from most of their English representatives.

Thus we find in the Mesozoic series of the Western Highlands that there occur in the Infralias beds in some localities a mass of sandstones with thin coal-seams; while the whole of the formations included between the *Parkinsoni*-beds of the Inferior Oolite and the middle portion of the Oxfordian are represented over a considerable area by a series of estuarine deposits, which probably attain in places to a thickness little short of 1000 feet. Even where distinct evidences of estuarine conditions are wanting in the Hebridean Jurassic strata, the deposits are clearly, as a general rule, of more littoral character than their equivalents in England—beds of conglomerates and other indications of the proximity of a shore-line making their appearance at a great many different horizons in the series.

We have pointed out the existence among the Jurassic deposits of the eastern coast of Scotland of two distinct types of strata of estuarine origin—one *argillaceous* or *calcareo-argillaceous* in composition, and resembling the Purbeck and Punfield series in the south; and the other mainly *arenaceous* in composition, and resembling portions of the English Hastings sand and Carboniferous formations. So strikingly, indeed, do the former class of strata—with their bands of limestone made up of *Cyclas*, *Cyrena*, or *Paludina*, their laminated shales crowded with Cyprids, their thick masses of dwarfed oysters ("cinder-beds"), and their seams of fibrous carbonate of lime ("beef- and bacon-beds")—resemble the series of deposits found at the base and summit respectively of the great English Wealden formation, that it is by no means surprising that, before their relations to the marine beds were made out, Murchison should have supposed that he had detected veritable Wealden deposits in the Western Isles.

But in the case of the Mesozoic series in the West of Scotland we find evidences of a still more interesting character, namely, that the tendency to a recurrence of estuarine conditions during the whole of the Jurassic period was continued all through the Upper Cretaceous. Although, as I have pointed out in my former paper, there is strong evidence that considerable patches of Cretaceous strata had

escaped removal by denuding forces up to so recent a period as the Glacial epoch, yet we have at the present time no certain evidence of the existence *in situ* of any deposits of that age in the Eastern Highlands. In the Western Highlands, however, I have been so fortunate as to detect such evidences; and they enable us to arrive at a number of conclusions concerning the physical conditions prevailing in the area in question during the Cretaceous period that are of the most striking significance and the highest interest at the present time.

In the west of Scotland, as in the north of Ireland, the lowest Cretaceous strata exposed are of Cenomanian (Upper Greensand) age, and, as in the latter district, they are of marine origin. Above these marine beds, however, there occurs a series of sandstones containing thin coal-seams and other evidences of the prevalence of estuarine conditions; and these are in turn covered by a singular marine representative of the highest beds of the English Chalk—the Zone of *Belemnitella mucronata*. Finally, the second series of marine beds is seen in places to be covered by other estuarine and coal-bearing strata, which may represent the highest members of the Cretaceous (the Maestricht, Faxoe, and Meudon beds), or may be intermediate in age between the Cretaceous and Tertiary, or, lastly, may constitute the base of the great Tertiary series of rocks in the Highlands.

This remarkable series of alternating marine and estuarine strata of Upper Cretaceous age—so different in character from the deep-sea representatives of the same formations in the other parts of our islands—is unfortunately only very imperfectly seen at a few not very accessible points; and they moreover make their appearance in such a manner from beneath the vast and overwhelming masses of Miocene basalts as to afford but scanty facilities for their study and for the collection of their fossils; but the fact of the existence of such beds in the extreme north-western part of our archipelago, especially in face of the great development of estuarine Cretaceous strata on the North-American continent, is one of the very highest interest. Nor is that interest lessened by the fact that we find in the same area proof of the presence of a Cretaceous shore-line in the beds of coarse conglomerate into which the strata in question are sometimes found to graduate.

The Poikilitic strata of the Western Highlands, though not yet proved to be fossiliferous, like their representatives in the east (the reptiliferous sandstones of Elgin, &c.), are by no means destitute of interest; and the circumstance that while, on the one hand, they can be shown to be distinctly superposed on rocks containing undoubted Carboniferous plants, on the other they are conformably overlain by Infra-Iassic strata, is of the highest importance in its bearing on the long and vexed controversy concerning the age of the equivalent strata in the Eastern Highlands.

Although the different members of the Mesozoic formations in the Western Isles exhibit, as is so frequently the case with strata of littoral and estuarine origin, very numerous and rapid changes in thickness and character within comparatively short distances, yet when all the evidence is pieced together by the aid of the palæonto-

logical key it is found that this portion of the British Islands must at one time have been covered with an enormous thickness of strata, intermediate in age between the Carboniferous and the Eocene. This thick mass of strata, which in places attained probably to a vertical thickness little, if any thing, short of a mile, was represented by the following members, here shown in a tabular form, with their maximum thicknesses :—

TABLE showing the Succession of the Mesozoic Strata in the Western Highlands.

Miocene Volcanic and Inter-volcanic rocks.		Maximum thickness. feet.
UNCONFORMITY.		
CRETACEOUS ...	1. Estuarine clays and sands, with coal	20+
	2. White chalk with flints (Zone of <i>Belemnitella mucronata</i>)	10+
	3. Estuarine sandstones, with coal	100
	4. Upper-Greensand beds	60
UNCONFORMITY.		
OOLITIC	5. Oxford Clay.....	?
	6. Great estuarine series.....	1000
	7. Lower Oolite	400
LIASSIC	8. Upper Lias	100
	9. Middle Lias	500
	10. Lower Lias	400
	11. Infra Lias	200
POIKILITIC ...	12. Conglomerates, sandstones, marls, and limestones	1000+
UNCONFORMITY ?		
CARBONIFEROUS. Sandstones, shales, and coals.		
UNCONFORMITY.		
OLDER PALÆOZOIC ? Gneiss rocks and Torridon Sandstones.		

It will be seen from the above Table that while the Poikilitic, the Liassic, the Oolitic, and Upper Cretaceous systems are all represented by deposits of very considerable thickness, several other members of the Mesozoic series have not as yet been detected on the west coast of Scotland. The principal formations found to be thus unrepresented there are the Upper Oolite and the Neocomian.

But I would ask the reader to call to mind the evidences, which I have already laid before this Society in a former communication, that the Upper Oolites are represented in the Eastern Highlands by deposits of great importance (probably not less than 1000 feet in thickness), and that there are some grounds for the inference that beds of

Neocomian age were likewise deposited in the same area, and at the same time to remember the evidence which there is of such enormous denudation having swept the district again and again during successive geological epochs; let him, too, reflect on the fact that beds deposited during the period in question would have the worst possible chance of surviving to the present day, in consequence of that wide-spread upheaval and erosion which preceded the Upper Cretaceous epoch; and keeping all these considerations before his mind, he will certainly hesitate before accepting the negative evidence in the case as final, and concluding from the absence now of any discoverable traces of the Upper Oolitic and Neocomian formations that deposition was not going on in any portion of this area during the periods in question.

On the enormous amount of denudation which must have taken place during the latter half of the Tertiary period, I have already dwelt in the earlier portion of this paper. In a former communication I showed how vast were the results effected in the removal of great thicknesses of rock during the earlier portions of the Tertiary period, before and during the long succession of eruptions from the great Hebridean volcanos; and now I must touch briefly on the great destruction of stratified masses which must have occurred in the period preceding the formation of the Cenomanian strata. The great unconformity between the Upper Cretaceous and all the older deposits on which it is found resting is a very striking feature both in the south of England, the Yorkshire area, and the north-east of Ireland; more than this, it is, as Professor Suess of Vienna has so well pointed out*, equally well-marked in the Alps and almost everywhere within the European area. But this remarkable unconformity and overlap is nowhere better exhibited than among the exposures of the Secondary strata in the Western Highlands and Hebrides, where the Scottish Upper Greensand is seen overlapping all the older formations and resting sometimes on the Jurassic, at others on the Poikilitic, and others, again, on the Older Palæozoic gneissic rocks. That this unconformity and overlap has been brought about by grand and widespread subterranean movements—elevation, denudation, and subsidence succeeding one another during long periods—no geologist can for a moment doubt. This being the case, we are certainly, as I have already hinted, prepared for, and the less surprised at, the absence of those members of the Mesozoic series that would be deposited immediately before the incidence of this epoch of change, and would consequently be the first to suffer during its revolutions. And in a district where only minute patches of older deposits have escaped destruction in consequence of a concurrence of accidents (of such remarkable character in themselves and occurring in such singular combinations), it would be idle for the geological interpreter to express surprise, however keen may be the regret he feels when he finds certain chapters of the record altogether missing.

* See his 'Entstehung der Alpen.' Vienna, 1876.

V. DESCRIPTION OF THE SECONDARY STRATA AND ASSOCIATED FORMATIONS IN THE WESTERN HIGHLANDS.

I will now proceed to give an account of the various formations which are found represented in the singular patches of strata that lie between the old gneiss rocks and Torridon Sandstones of the Highlands on the one hand, and the great masses of superimposed Tertiary lavas on the other. The Carboniferous, Poikilitic, and Cretaceous systems, as here represented, will demand detailed description at my hands, as they have not before been noticed. With respect to the Jurassic strata, however, I shall only treat generally of those accessible and tolerably well known sections which have been illustrated by the writings of other geologists; and wherever it is possible to do so, I shall simply refer to lists of fossils already published in this Journal, reserving to myself, however, more latitude in describing the sections hitherto noticed but imperfectly or not at all, and seeking especially to illustrate the changes which the several formations are found to undergo as they are traced over considerable areas.

Even when thus limited, however, I find that the present part of this memoir will extend to a somewhat excessive length, and I am compelled to relinquish the intention I once held of describing, either by myself or with the assistance of others, the new forms of life which I have obtained during my studies. Some of these new forms are undoubtedly of very considerable interest; but it is desirable that they should be described in monographs treating especially of the life-groups to which they belong rather than in connexion with a memoir devoted to the discussion of problems like those with which we are at present concerned.

A. THE CARBONIFEROUS SYSTEM.

Very interesting, indeed, as affording a well-characterized base on which the remarkable series of Mesozoic strata which we are describing repose, is the mass of Carboniferous rocks which I had the good fortune to discover in Morvern in the year 1877. Like the Secondary rocks which are superimposed upon them, these Carboniferous deposits are a mere vestige of a doubtlessly once widely spread formation which, as the consequence of a concurrence of remarkable accidents, has escaped total destruction through denudation. The patch now remaining for our study is excessively small, extending only for a few hundreds of yards along the shore—on the east being suddenly cut off by a great fault with a throw of something like 2000 feet, and on the west being overlapped and concealed by the superincumbent Poikilitic strata.

What is still more unfortunate is, that these remarkably isolated Carboniferous beds are exposed only in a series of tangle-covered reefs in front of the wild ravine of the Innimore of Ardtornish, and these are uncovered by the sea only at low water during spring-

tides. Hence the geologist has to wait for a favourable concurrence of suitable low tides with an off-shore wind in order to be able even to approach the object of his quest.

Small in extent, however, as is this outlying patch, and difficult of access, it fortunately yields to us most unmistakable and satisfactory evidence of its age and characters. I have several times succeeded in reaching the spot when the conditions were favourable for its examination—sometimes by traversing the face of the grand basaltic cliffs of Ardtornish, at other times by means of a boat from Loch Aline or the opposite shore of Mull. During the last season I had the pleasure of visiting the locality in company with Dr. Taylor Smith, during very stormy weather, it is true, but at a time when the other conditions were particularly favourable for the study of the rocks.

These beds of the Innimore of Ardtornish consist of somewhat coarse white sandstones, and of fine-grained highly micaceous sandstones of a very dark tint, passing occasionally into shales. Both the coarse-grained and the fine-grained rocks are crowded with plant-remains, which in the former exist as hollow casts, and in the latter retain their carbonaceous matter. Occasional thin and imperfect seams of coal occur, and the agreement in physical characters of this most northern patch of Carboniferous strata with the strata of the same age in other parts of our islands is most complete and striking.

Fortunately, too, the palæontological evidence as to their position in the geological series is of the most satisfactory character. The plant-remains, though abundant, are seldom sufficiently well preserved for specific determination. Among the forms which I have been able to detect as occurring there are:—

Lepidodendron aculeatum, *Presl.*
Calamites Suckowii, *Brongn.*
 — *Cistii*, *Brongn.*

Sigillaria Saullii, *Brongn.*
Stigmaria.

The only specimen of *Lepidodendron* which I have been able to obtain is an example more than a foot in diameter. This and the species of *Calamites* afforded the most satisfactory evidence concerning the age of the strata.

I may add that my recognition of the age of these deposits is supported by the opinion of the most competent palæophytologists from the examination of the specimens obtained. Sir Charles Bunbury, to whom my earliest specimens were sent by the late Sir Charles Lyell, and Mr. Carruthers and Professor Morris, who have examined a somewhat larger series, all agree that it is impossible to refer the plant-remains to any other horizon than the Carboniferous.

This series of Carboniferous strata, where best exposed, cannot exceed 40 or 50 feet in thickness; its relations, however, are unfortunately by no means very clearly exhibited. That it reposes directly upon the gneissic rocks of the district there is every reason for believing; for these rocks compose the islands of Ridire and the Grey-Island group, which rise above the waters of the Sound of Mull be-

tween the Innimore of Ardtornish and the opposite shore of Mull; and that it is unconformably superposed on these old rocks there can be little room for doubting. We have already mentioned that the Poikilitic beds of the reefs to the west and in the cliff-section of the Ardtornish ravine clearly lie above the Carboniferous strata; but as to the question whether an unconformity exists between these two series, I have altogether failed in obtaining satisfactory and conclusive evidence, so imperfect are the exposures at this locality.

The wonderful interest attaching to these Carboniferous strata—forming a patch so minute in dimensions and so isolated in position—arises from the fact that they afford evidence of the extension of strata of the Carboniferous age into areas in which they were formerly unknown and were believed never to have been deposited. Sir Roderick Murchison and other authors have argued that the absence of Carboniferous rocks in the Scottish Highlands must be accepted as proof that such strata were never deposited in the area, and that the rocks now forming that mountain district constituted at a period so early as the Carboniferous a continuous land-surface. But here, as in so many other cases in the same district, we find a most striking illustration of the effects produced by denuding agents during past geological epochs, and a warning as to the necessity for exercising the greatest caution in drawing deductions from the absence of strata in a given area as to whether they were ever deposited in it.

B. THE POIKILITIC SYSTEM.

To the indefatigable and sagacious Macculloch we are indebted for first pointing out that there exists in the Western Highlands at Gruinard Bay evidence of a series of Red Sandstone strata unconformably overlying, and therefore of far later date than, the great masses of Red Sandstone (Torridon Sandstones) which constitute a grand and widely spread formation in the north-western part of the British archipelago. Macculloch, Murchison, Sedgwick, and Nicol, assuming (as was universally done by the earliest students of Highland geology) that the Torridon Sandstone represented the "Old Red," saw that the most probable position to assign to the unconformable strata would be that of the "New Red." Prof. Nicol has added many new and exact details concerning these interesting beds in a paper read before this Society in 1857*.

But it is evident that the admission, now very generally made, that the Torridon Sandstones are of older date than the Old Red, once more places the question of the age of the overlying deposits in a state of uncertainty.

Other deposits of similar character to the strata of Gruinard Bay have been referred to as existing in Raasay, and by Dr. Bryce were thought to be possibly of Rhaetic age.

These and a great number of scattered masses of conglomerate, sandstone, marl, and concretionary limestone I have now been able

* Quart. Journ. Geol. Soc. vol. xiv. p. 167.

to correlate with one another, to show that they constitute portions isolated by denudation of a once widely spread formation which attained to a very great thickness, certainly exceeding 1000 feet, and to demonstrate that this formation rests upon Carboniferous, and overlaps older strata, and is covered conformably by the strata of Infra-lias, Lias, and Oolite age. Further, it has become manifest to me during my study of the district, that the strata in question present the closest agreement in physical characters with deposits on the eastern side of Scotland which have been rendered famous by the controversy concerning the vertebrate remains which they contain: I refer to the Reptiliferous Sandstone of Elgin and the accompanying Stotfield rock. Under all the circumstances of the case we can have little hesitation in referring all the strata in question, which have so wide a distribution in Sutherland, Elgin, Ross, Argyllshire, and in a number of the Hebridean islands, to that series of formations which in our islands intervenes between the Carboniferous and Jurassic systems, and for which the name of Poikilitic has been suggested by Conybeare and revived by Huxley. The Poikilitic strata of the Highlands present striking resemblances, in their physical characters, their stratigraphical relations, and their fossil contents, to the beds of the same age in the more southern districts of the British Islands.

These Poikilitic strata of the Western Highlands consist of a very variable series of deposits—breccias and conglomerates alternating with variegated sandstones, clays, and impure concretionary limestones. The conglomerates are, in some instances, found to be composed of perfectly well-rounded pebbles; more frequently, however, the fragments of which they are made up are subangular; and occasionally they retain their unworn edges and angles, and the rock thus passes into breccia. The associated sandstones are usually coarse-grained, and show a tendency to become, in places, conglomeratic, while false-bedding, ripple-marked surfaces, and clay-galls are phenomena very frequently exhibited by them. The clays, which are often more or less sandy, are usually of red, green, or mottled tints, and strikingly resemble the so-called “marls” of the English Poikilitic. The limestones are usually very impure in composition—sometimes argillaceous, at others sandy in character; and they are not unfrequently associated with, and pass into, a rock of siliceous composition.

The materials forming the breccias, conglomerates, and coarser sandstones have evidently been derived directly from the rocks on which the Poikilitic strata at the particular locality repose—usually either the Torridon Sandstone or some member of the great gneissic series of the Highlands. One feature which the Poikilitic conglomerates and sandstones all present, and which serves to distinguish them from all other similar strata in the Highlands, is the abundance of calcareous material which enters into their composition. Not only do fragments of compact limestone (derived probably from the Durness or other calcareous beds now wholly removed by denudation) abound in these strata, but their particles are frequently united by a cement of carbonate of lime, the sandstones thus

passing into calcarous grits, and some of the clays becoming true marls. The beds are frequently found to be traversed in all directions by innumerable veins of Calespar.

That the limestones are of chemical and not organic origin is evident both in the case of the beds in the Western Highlands and in that of the equivalent "cherty-rock of Stotfield," with which they so closely agree in character. From a study of all the features of these Poikilitic strata of the Highlands, I am inclined to accept the suggestion first made by Mr. Godwin-Austen, and afterwards supported by Prof. Ramsay, with regard to their English equivalents—namely, that they have been accumulated in inland lakes and not in the open ocean. In the Poikilitic strata of the island of Inch Kenneth some irregular beds and veins of gypsum occur; and these, though of no considerable thickness or importance, constitute another point of resemblance between the Highland strata and their equivalents in the southern part of the kingdom. Beds of rock-salt, it is true, do not occur in them; but in almost every other respect the resemblance between the Poikilitic strata in the northern and southern areas of Britain is of the most marked character.

The Poikilitic Series of the Western Highlands varies greatly in the thickness and order of succession of its beds. While at Gruinard Bay it certainly exceeds 1000 feet, in Raasay it is probably less than one half that thickness, and at Lussay, in Skye, it is reduced to a few feet only. At Ru-Geur, in Sleat, the formation shows signs of regaining somewhat of its thickness and importance, which characters it certainly retains in Ardnamurchan and some points in Mull, while in Morvern it is probably not less than 1200 feet thick in some places, whilst in others it is reduced to comparative insignificance. As a general rule, the breccias and conglomerates prevail in the lower parts of the series, sandstones, clays, and limestones in the upper; but everywhere the succession of beds is most irregular and inconstant, thick and important members thinning out and disappearing or totally changing their characters within very short distances.

None of the Poikilitic rocks of the west of Scotland have as yet yielded fossils capable of determination; with the exception, indeed, of a few imperfect casts of bivalve shells (*Cyrena?*) which I found some years ago in a quarry at Ardtornish Towers, I know of no traces of organic remains occurring in the beds. In spite of this absence of fossils, however, their position in the geological series is placed beyond doubt by the following facts:—

- (1) They conformably underlie the Infralias strata of the district.
- (2) They unconformably overlie and overlap the Carboniferous and other Palæozoic rocks.

- (3) They agree most strikingly in character with strata on the east coast of Scotland, of which the age has been demonstrated by a concurrence of palæontological and stratigraphical evidence.

Whether particular portions of the strata should be referred to the formations which are elsewhere relegated to the Permian, Trias, and Rhætic respectively, we are at present wholly unable to determine.

In addition to these general remarks on the stratigraphical relations of the Poikilitic strata of the Western Highlands, it is only necessary to add that at Gruinard Bay, in Raasay, and in Sleat these strata rest on the Torridon Sandstones; in Strath, Ardnamurchan, Inch Kenneth, Gribun, and round Loch Arienas on the old gneissic rocks of the county; and at the Innimore of Ardtornish upon Carboniferous deposits. At Gruinard Bay they are not seen to be covered by any younger formation except the glacial deposit; but at Raasay, Sleat, and Ardnamurchan they are followed by highly fossiliferous Infraalias strata, apparently everywhere in perfectly conformable succession; while at Sleat, Inch Kenneth, Gribun, Loch Aline, and in the remarkable outliers of Morvern they are unconformably overlain, sometimes by the Upper Cretaceous strata, and at others by the great masses of Tertiary lava.

After this general account of the formation in question, it will only be necessary to add some remarks on the peculiarities presented by the different sections of its beds, which occur over an area stretching nearly 120 miles in length, from Gruinard Bay in the north to Gribun in the south.

At Gruinard Bay the Poikilitic strata are well exhibited in a succession of sea-cliff and shore-reef sections, stretching for a distance of over three miles. Inland they are wholly covered and concealed by boulder-clay and peat-mosses. As already pointed out, they owe their position and preservation to the action of grand faults of certainly vast but indeterminate amount of throw, by which they are brought far below their original position and troughed into the heart of the Torridon-sandstone masses. Several parallel faults traverse this down-dropped relic of strata; and its beds show many signs of the subterranean disturbances to which they have been subjected* (see the section, fig. 1, p. 671).

The unconformable relations of these Poikilitic deposits to the Torridon sandstones, on which they rest, has been dwelt upon and well illustrated by both Macculloch† and Nicol‡, who have accomplished so much in unearthing the secrets of Highland geology. These unconformable relations are of the most striking and unmistakable character—the Poikilitic beds dipping generally W. or N.W., while the underlying Torridon sandstones lie at very high angles, with varying strike, and are sometimes vertical and at others contorted. The little sketch of a boat-house given by Prof. Nicol, the walls of which are formed of Torridon sandstone, and the roof of Poikilitic strata, serves to give some idea of the very striking appearances that may be witnessed along this interesting shore. The section I have already given shows how the Poikilitic strata are bent into gentle folds, and are faulted and interrupted along the shores of Gruinard Bay.

In company with my friend Dr. Taylor Smith I estimated the thickness and succession of the Poikilitic beds as exposed in a continuous series of sections between the salmon-house west of Sands,

* 'Western Isles of Scotland', Atlasplate xxxii. fig. 8.

† Quart. Journ. Geol. Soc. vol. xiv. p. 168.

‡ *Ibid.* vol. xiv. (1858), p. 168.

and the farmhouse of Udrigle, where the upward succession is abruptly terminated by the western fault. After making every possible reduction, and checking our estimates of the breadth of outcrop of the several members by means of the large and accurate Admiralty Chart, I feel justified in stating the following to be the succession and approximate thicknesses of the strata at this locality. The section given proceeds from the base upwards.

(1) Coarse breccia-conglomerates of subangular fragments of sandstone, quartzite, limestone, &c., alternating with red and mottled, false-bedded, often argillaceous sandstones, with a few pebbles scattered through their midst, the whole being traversed by many veins of white calc-spar; where in contact with the underlying Torridon Sandstones the larger fragments are all evidently derived from that formation, and are sometimes almost perfectly angular and of considerable dimensions. In the lower part of this series the breccia-conglomerates certainly preponderate over the sandstones; but in the higher parts the former are found gradually to become less and less prominent, and towards the summit only occasional bands of conglomerate occur in the midst of thick masses of argillaceous strata. This series is certainly of very great thickness, the lowest possible estimate being 500 feet.

(2) The argillaceous sandstones of the lowest member of the series graduate upwards almost insensibly into thick masses of red and variegated clays and marls, which in places are very sandy in character. These very strikingly resemble portions of the English Keuper, and only occasionally contain thin sandstone bands, which are sometimes conglomeratic. Some beds of sandstone of a sea-green colour, and irregular bands of impure concretionary limestone, also occur in this part of the section. In its upper part this member of the Poikilitic exhibits a preponderance of arenaceous over argillaceous strata, and conglomerates become more common; its thickness is certainly over 200 feet.

(3) Soft reddish argillaceous and sandy beds in alternating succession, with some bands of white and greenish sandstone and grit, which, on account of their hardness and power of resisting atmospheric denudation, often stand out very prominently in the cliff-section. Conglomeratic beds are exceedingly rare in this part of the series, which certainly exceeds 200 feet in thickness up to the point where the upward succession is abruptly terminated by the great fault.

These three divisions of the Poikilitic, which, however, are not in any way sharply divided from one another, as seen at Gruinard Bay, have each their analogues, which seem to follow one another in somewhat corresponding order, at several other localities where the same strata are exposed in the Western Highlands.

The next point at which, in proceeding southwards from Gruinard Bay, we detect traces of the Poikilitic beds, is in the island of Raasay. Here there occur two very interesting sections. At one of these, situated at the point called Ru-na-Leac, the highest beds of the formation are seen unconformably underlying all that

series of Jurassic strata which is so finely exposed in the magnificent precipices of Hallaig and Screpidale. The strata which are here seen in passing downwards from the Infralias rocks that lie immediately and conformably above them are as follows :—

- (1) White, reddish, mottled, and ferruginous sandstones, exhibiting much false bedding, and becoming conglomeratic in places. These beds contain many limestone fragments, and in places much calcareous matter in their matrix. Their thickness is at least 80 feet.
- (2) Red and mottled clays and marls, often very sandy, and sometimes conglomeratic. These beds pass in places into true sandstones and conglomerates, and contain some bands of concretionary limestone. Thickness 60 feet.
- (3) Conglomerates (formed of rounded or subangular fragments of white and purple quartzite, of Torridon Sandstone, and of compact or subcrystalline limestone) alternating with irregular lenticular beds of coarse micaceous sandstone, into which the conglomerates often insensibly graduate. These beds exhibit reddish and greenish tints, and closely resemble in character the lowest beds of Gruinard Bay. Thickness seen 60 feet.

This series of strata is thrown against beds of Middle-Lias age by the great Hallaig fault, which has a throw of at least 700 feet (see fig. 2, p. 671). It is probable that these 200 feet of strata at Ru-na-Leac comprise nearly the whole section of the Poikilitic in this island; but as the Torridon Sandstones have not been seen to make their appearance from beneath the conglomerates even at the lowest tides, it is impossible to speak with certainty upon the question.

At a point called Ayre, in the same island of Raasay, and lying south of Ru-na-Leac, there is found a conglomerate resting unconformably upon the Torridon Sandstone, and largely made up of its fragments, but with the addition of some pebbles of limestone; and this, there can scarcely be the smallest doubt, belongs to the base of the series, all the upper beds having been removed by denudation.

At Castel Brochel, in Raasay, several miles to the north of Ru-na-Leac, another mass of conglomerate makes its appearance upon a projecting headland, on which the famous and singularly situated old Highland stronghold is perched. As the conglomerate in question, however, is very different in many of its characters from the Poikilitic beds of the area, especially being distinguished from them by containing no limestone fragments as well as in its general aspect, and as, moreover, the relations of the isolated patch of conglomerate are of a doubtful and indeterminate character, I find no grounds on which to assign it either to the Poikilitic or to any other part of the Secondary series of strata.

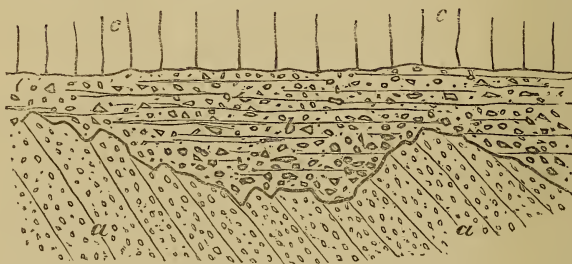
The Poikilitic beds in Raasay appear to have a much less thickness than those of Gruinard Bay; and when we proceed southward into Skye that thickness is found still further diminished, and the formation in question is thus reduced to a merely rudimentary condition. Beds of pebbles, constituting a thin conglomerate band, have been detected at several points at the junction of the Jurassic strata and the Torridon Sandstone at Strath in Skye. In the coast-section at Lussay there is evidently an interval between the Jurassic rocks and the Torridon Sandstones that unconformably underlie them; but the strata in this interval are only very imperfectly exposed even at the

lowest spring-tides. So far as I have been able to determine, after several investigations of this locality, the downward succession of beds below the Infralias seems to be as follows:—

- (1) Thin band of sandy clay containing irregular calcareous concretions.
- (2) Variegated marls and clays (red, greenish, and mottled).

These strata are very thin; and it is probable that they are underlain by some conglomerate beds, which, however, are wholly concealed in the coast-section.

Fig. 7.—Section of *Poikilitic Beds at Ru Geur, near the Southern extremity of Sleat, Skye.*



a. Torridon Sandstones.

b. Poikilitic strata.

c. Phonolitic rock (columnar).

In the singularly preserved patch of Ru Geur, in Sleat, previously referred to, a very remarkable relic of the Poikilitic series is found interposed between a foundation of Torridon Sandstone and a capping of finely columnar Tertiary phonolite (see fig. 7). Not more than 15 or 20 feet of the beds in question are here exposed; but so similar is the rudely stratified mass, consisting of alternating lenticular beds of fine and coarse conglomerates, composed mainly of Torridon Sandstone, but with a fair percentage of quartzite and limestone pebbles and a tolerable quantity of calcareous matter in its matrix, that there is little room for doubting that these strata should be referred by us to the Poikilitic period.

In going still farther southwards it is in Ardnamurchan that we find the next exposures of the Poikilitic series; and here they have evidently reacquired some of the thickness and importance which, as we have seen, they had lost in Skye.

At Surdil, on the north coast of Ardnamurchan, we find that the beds of highly contorted gneiss have their eroded hollows filled by masses of angular fragments of the same rock; and these are covered by conglomerates and sandstones, above which appear the Infralias limestones with well-marked fossils. Although it is certain that at Surdil the Poikilitic beds are present and of considerable thickness, yet so broken up are the strata by faults, so traversed and interrupted are they by igneous dykes and sheets, and so masked are their characters by metamorphic action, that it is impossible to make

out any very clear order of succession among the beds or to estimate their total thickness with any approach to accuracy.

The same remark applies almost equally to the section on the south side of the Ardnamurchan peninsula, to the east of Mingary Castle. Here it is evident that beds of breccia and conglomerate, made up of gneiss, quartzite, and limestone pebbles, and often having a calcareous matrix, are interposed between the old gneiss rocks and the here greatly metamorphosed Infralias limestones. But neither in the coast-section nor in the exposures of the same strata inland, in the interval between them is it possible to obtain any satisfactory order of succession or correlation of beds, where all have been subjected to such violent subterranean movements, igneous intrusion, and profound metamorphism in consequence of the proximity of the great Miocene volcanic centre of Ardnamurchan, and the long subsequent action of the far inferior but by no means insignificant igneous extrusions of Beinn Shiant.

In Morvern the Poikilitic strata evidently attain in places considerable thickness and importance; but both the order of succession of beds and the degree of development of the whole mass exhibit most wonderful diversities within very short distances.

Around Loch Arienas, under three of the great outlying patches of basalt that lie on the north side of that lake and the arm of the sea called Loch Teachdaish, and again near the head of Loch Aline and at the base of the cliffs of Ardtornish, we everywhere find the variegated sandstones and marls, the calcareo-siliceous rocks, the coarse conglomerates and breccias, so characteristic of this series of deposits. At Ardtornish Towers is a rather deep quarry in the coarse and conglomeratic sandstone of pink and greenish tint, almost wholly made up of quartz pebbles. This quarry is remarkable as having afforded the only traces of fossils of the Hebridean Poikilitic strata; and these are, as we have seen, of the most imperfect character. The conglomeratic sandstones of Ardtornish Towers, of which some 50 or 60 feet are exposed, though the bottom is not reached, are covered by beds of red and white clays and sands, with masses and layers of concretionary limestone, strikingly similar in character to the cherty rock of Stotfield.

It would be of little service to give details of the numerous small exposures of these very variable strata. Suffice it to say that everywhere in Morvern we find the general order of succession to be (from above downwards):—

- (1) Red, green, grey, and variegated sands and sandy marls.
- (2) Concretionary limestones, sometimes of considerable thickness.
- (3) Red marls and some sandy beds.
- (4) Coarse conglomerates, grits, and sandstones, with breccias at the base.

We may further remark that the thickness of these several members is most inconstant, the total varying from a few feet only in Beinn-y-Hattan to about 200 feet near Kinloch Aline, and 400 or 500 feet at the Innimore of Ardtornish.

Wherever the Poikilitic series is complete in Morvern it is covered

conformably by the Infralias limestones; but at many points its members are seen to be overlapped by the Cretaceous beds.

It is very characteristic of the Poikilitic beds to vary wonderfully in thickness and character within short distances. Nowhere is this more strikingly illustrated than in the two opposite sides of the Sound of Mull. On the Morvern side of the Sound, at the Innimore of Ardtornish, the series is some 400 or 500 feet thick; but on the Mull side, at Craignure (Auchnacraish), it is found to be reduced to an insignificant amount. The strata at this latter locality are greatly metamorphosed, the sandstone pebbles being converted into quartzite and the limestone into marble, and the colours of both frequently discharged. The igneous intrusions are so numerous and complicated that the exact thickness and succession of beds in it is as difficult to estimate as in the analogous case of Ardnamurchan. At the very base of the series, and lying directly on the older rocks, is a breccia composed of angular fragments of gneiss and quartzite; but this can only be seen at low water during spring-tides.

In Duart Bay, and at some other points along the west side of the Sound of Mull, we find more or less distinct traces of the beds of the Poikilitic series. In some of these cases the exposures are so small, and in others the beds have undergone such an amount of metamorphism, that it would be idle to attempt to do more than chronicle their existence. In some cases, as opposite to Calla Island and below the precipitous cliffs of Toum Peroch, there are strata which, in their isolated position and their altered condition, it is impossible to state absolutely to belong to the Poikilitic, though perhaps the balance of evidence is in favour of such a determination. The consideration of the age of these doubtful deposits need not, however, detain us further.

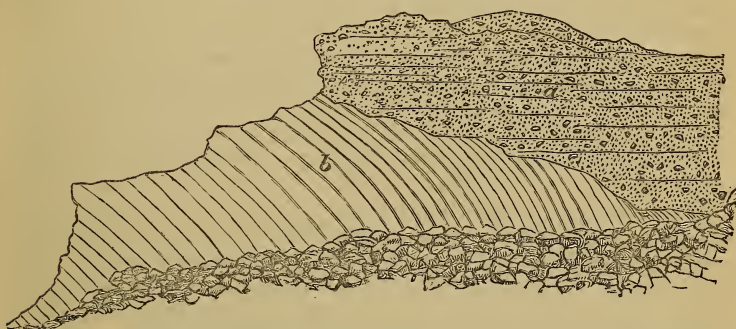
The last point towards the south where the Poikilitic strata are seen is in the small island of Inch Kenneth, on the west side of Mull, and on the shores of the peninsula of Gribun, opposite to it. Here the unconformity between the Poikilitic strata and the older rocks, which here consist of purplish quartzite and gneiss, is quite as beautifully exhibited as at Gruinard Bay; and the following sketch taken near the little cave known as Beg's Cave will afford a good idea of the relations of the strata at this point (see fig. 8).

On the eroded edges of the old metamorphic rocks, which lie in vertical and contorted positions, lies a very coarse conglomerate, often containing angular and subangular fragments, a breccia composed of such fragments being always found at the base. Tracing the conglomerates upwards we find them alternating with and passing into irregular bands of greenish and mottled sandstone, with some beds of concretionary limestone and occasional marly beds and thin layers of gypsum.

The thickness of the Poikilitic strata at Gribun is considerable; and their summit is not seen, as they are unconformably overlapped by the beds of the Cretaceous series. Indeed, as we shall see hereafter, the beds of the Upper Greensand are so similar in character, being made up of materials derived from the Poikilitic, that it is

impossible to draw any sharp line of demarcation between them, though their difference of age is so enormous, and in other localities they are separated by thousands of feet of strata. To the west the Poikilitic strata of Gribun, with the overlying Cretaceous, rise gradually in the cliff till they are overwhelmed and concealed by the vast taluses descending from the overhanging basaltic precipices of the grand peninsula of the Bourg. It is probable, too, that they are cut off to the west by a great fault, which carries them below the sea-level.

Fig. 8.—*Sketch taken near Beg's Cave, on the Southern Shore of Loch na Keal, opposite Inch Kenneth.*



a. Conglomerates and sandstones of Poikilitic age, covered by Cretaceous (Upper Greensand) strata.

b. Purple quartz, quartz-schist and gneiss.

In concluding this account of the Poikilitic strata of the Western Highlands, it is impossible to abstain from again expressing the strongest protest—a protest based on convictions that have gained strength with successive years of work in the district—against the acceptance of negative evidence in this case, and against the view that similar strata to those exposed at so many points between Gruinard Bay and the Gribun might not originally have extended far beyond those limits. When we look southward to Antrim and northward to Sutherland and Elgin, where beds of similar age and character reappear, we cannot but feel that it is impossible to limit the former extent of this formation to the particular regions wherein traces of it have been accidentally preserved, or to avoid the conclusion that wide areas now exhibiting no traces of deposits of this age were once buried under hundreds, or even thousands, of feet of the Poikilitic beds.

C. THE JURASSIC SYSTEM.

As already pointed out in the introduction to this paper, the fact of the existence in the Western Islands of Jurassic deposits of considerable thickness and importance has long been known to geolo-

gists. The results, moreover, of the labours of Murchison, Geikie, and Bryce, as interpreted by the palæontological studies of Sowerby, Forbes, Wright, and Tate, leave us little room for doubt as to the true correlation of the various strata which are seen in the grand sections of Skye and Raasay with the equivalent deposits in England. As these results, accompanied by detailed lists of fossils, are published at various times in the Transactions and Journal of this Society, and have further been very well summarized in the 'Catalogue of the Western Scottish Fossils,' the introduction to which is from the pen of Dr. John Young, it will be quite unnecessary for me to recapitulate the conclusions which have been already arrived at.

But, inasmuch as a great number of the less accessible sections of the Jurassic rocks in the Western Islands have hitherto been very imperfectly described, while some have hitherto remained altogether unnoticed, it seems to me desirable to consider these in connexion with those concerning which we already have a considerable amount of information. By doing so I hope to be able to show what was the distribution of the several members of the Jurassic series in this district, to illustrate the remarkable changes in character which some of them are found to undergo when traced over considerable areas, and thus to pave the way for arriving at a satisfactory basis on which to found a discussion concerning the physical geography of the district and of the conditions which prevailed in it during the periods when these strata were deposited. At the same time I shall endeavour to correct and supplement the previously published account of the old and familiar sections, whenever such correction and addition may be found necessary.

a. *The Infralias.*

The strata which underlie the *Lima-* or *Bucklandi*-beds in Western Scotland acquire at some points such thickness and importance that it will be convenient to follow the example of French authors, and to separate them from the remainder of the Lower Lias under a distinctive title. The formation in question certainly in places exceeds 150 feet in thickness, and includes strata both of marine and estuarine origin. Even the marine beds, however, very commonly exhibit clear evidence of the prevalence of littoral, and sometimes of brackish-water conditions, during their accumulation; and the whole formation thus constitutes a transition series between the probably lacustrine Poikilitic below and the undoubtedly marine Lower Lias above. The dwarfed forms of the oysters and other shells of the Infralias of this district, and the absence of the Cephalopoda from it, may be cited as warrant for these observations; but it must at the same time be remembered that some purely marine beds, crowded with corals and univalves, also occur in its midst.

The most conspicuous and characteristic strata of the Infralias are certain very hard bluish-grey limestones, sometimes compact, at others subcrystalline, and occasionally oolitic in structure. These limestones are not unfrequently found to be crowded with

fossils; but such is the hardness and intractability of the matrix in which they are enclosed, that it is seldom possible to disengage them in any thing like a satisfactory condition. Certain beds crowded with specimens of *Ostrea irregularis*, Münst., occur in the series, and others almost wholly made up of corals; and these latter beds abound with species of Gasteropoda, few of which, however, can be obtained in a sufficiently perfect condition for specific determination.

The limestones above described alternate with beds of sandstone and calcareous grit, which often contain numerous pebbles of quartz, and occasionally pass into conglomerates. At Applecross, where they can be very conveniently studied, these arenaceous strata intercalated in the Infralias are clearly of estuarine origin, and contain thin and imperfect seams of coal; but in Skye, Ardnamurchan, and Mull the sandy strata of the Infralias, though clearly of littoral origin, appear to contain marine fossils throughout.

There seems to be no room for doubt that the Infralias strata of the Western Isles are perfectly conformable with the subjacent Poikilitic, into which in some cases they appear to graduate downwards insensibly. The locality in which the details of the series of strata can be best studied is that of Applecross; but here the thickness of the series cannot be determined; on the shore of Raasay, opposite to Applecross, this thickness can be estimated, though the details cannot be well made out. The result of a careful examination of the question shows that the thickness of the Infralias in Raasay and Applecross cannot be less than from 150 to 200 feet; while in Strath in Skye, as seen between Lussay and Obe Breakish, the formation has at least an equal development. In the interior of the island of Skye, about Kilbride and Loch Slapin, the Infralias limestones, repeated by faults, are found to be greatly altered in consequence of the proximity of the great intrusive masses, and pass into fine saccharine marble and opicalcite, as described by Dr. Macculloch and Prof. Geikie. The sandstones which alternate with the limestones are changed into quartzite.

The Infralias, when traced southwards from Applecross, Raasay, and Skye, is found gradually to lose its importance, and to become diminished in thickness. While in Ardnamurchan the strata in question are moderately well developed, in Morvern and Mull they are seen to be reduced to a comparatively rudimentary condition. Possibly in the extreme south of the island of Mull they regain something of their former thickness; but, unfortunately, the rocks are here so greatly altered, and their fossils so completely obliterated through their proximity to igneous intrusions, that it is impossible to arrive at any certain conclusion as to where one formation ends and another begins.

It is worthy of remark that in the Infralias of the west coast of Scotland the "*Zone of Avicula contorta*" does not appear to be distinctly developed.

The section of the Infralias strata at Applecross is probably without its equal in the British islands, whether we regard the thickness of the strata representing the period, or the variety and beauty of

their fossil contents. Instead of the thin beds which occupy this horizon in England, we find thick masses of limestone alternating with estuarine strata, the former resembling the equivalent beds of Western France, the latter those of Scania. Unfortunately the complete series of the beds and their relation to the overlying deposits cannot be traced in any one continuous section, and the fossils, though numerous, are enclosed in so hard a matrix as to be very difficult of extraction. At the burn called Allt-Breugach and in a tributary stream a tolerably good succession of the strata can, however, be made out. The remarkable relations of this singular patch of Jurassic strata, and the curious combination of circumstances to which it owes its preservation, have been already commented on, and are illustrated by the plan and section (fig. 3, p. 672). Where the Cambrian sandstones are faulted against the calcareous beds of the Infralias the line of junction is very well marked, the copious streams which flow over the first-mentioned rocks being immediately lost in swallow-holes on reaching the latter.

The succession of strata of Infralias age at Applecross is as follows (in descending order):—

	ft.	in.
(1) Oolitic limestone with <i>Cardinia concinna</i> and other shells, with beds of shelly limestone below crowded with <i>Ostrea irregularis</i> .	50	0
(2) Alternations of limestones with calcareous grits and shales, and occasional beds of Oysters. (The thickness of (2) is considerable, but could not be exactly determined.)		
(3) Great series of sandstones, grits, and conglomerates with coal-seams, exhibiting clear evidence of shallow-water and estuarine conditions. This series is about 30 ft. thick, and exhibits the following members in the Allt Breugach:—		
a. Thick-bedded sandstone and grit (occasionally calcareous), forming a well-marked escarpment at the highest point at which the Jurassic beds are exposed in the Allt Breugach. The only fossils found were fragments of a gigantic <i>Pinna</i> near the base of the bed	11	0
b. Bed of conglomerate with scattered pebbles of white and pink quartz		9
c. Masses of sandstone similar to a, but generally more thinly bedded, passing into soft occasionally ferruginous sands on the one hand, and into fissile sandy beds on the other. These fossil beds contain spines of <i>Acrosalenia</i> and <i>Cidaris</i> , ossicles of <i>Pentacrinus</i> , and small univalves. Some others among the beds pass into a coarse calcareous grit, while in portions of the mass small quartz-pebbles are found abundantly scattered	12	0
At one point in this series of beds an inconstant seam of coal, of good quality but only an inch or two in thickness, was exposed in 1872, when I first visited this section.		
d. Thick bed of hard sandstone passing into calcareous grit, pebbly in places, and containing a few shells of <i>Ostrea</i> filled with crystallized carbonate of lime.....	3	6
e. Laminated sandy shales of a light blue colour, with a few bands of hard grit	1	3
f. Bed of hard blue calcareous grit	2	0
g. Bed of hard blue ferruginous shale indurated in some places...	2	6

At this point an intrusive sheet of coarse dolerite, about 6 feet in

thickness, destroys the continuity of the section. It alters in a very marked manner both the beds above and those below it.

	ft.	in.
(4) Alternating beds of shale and calcareous grit with few fossils, except casts of univalves	14	0
(5) Bed of grey compact limestone with partings of clay. Fossils are by no means rare in this bed, but are very imperfectly preserved. Among them occur spines of <i>Acrosalenia</i> , shells of <i>Ostrea irregularis</i> , <i>Lima Hermannii</i> (?), <i>Phasianella</i> (?) sp., <i>Rhynchonella</i> sp., and <i>Thecosmilia Martini</i>	6	0
(6) Shales and sandy beds imperfectly seen, passing downwards into hard calcareous grits with carbonaceous markings, which alternate with dark blue shales. These beds contain only few and very imperfectly preserved fossils	20	0
(7) Beds of hard argillaceous limestones, compact or occasionally oolitic, sometimes becoming sandy in character; these alternate with dark blue shales containing nodular bands of hydraulic limestone of a whitish colour. The limestones are occasionally crowded with univalves and corals, and sometimes almost made up of shells of <i>Ostrea irregularis</i> . Other fossils are common, but very difficult of extraction.		
(8) Below the last beds of limestone are found traces of another series of estuarine strata (exposed near the old mill of Applecross), which consists of soft yellow sandstones, grits, and conglomerates, in the lower part of which a coal-seam of some thickness was once exposed		?
The base of this series is not seen.		

Unfortunately this interesting section of the Infralias strata in Applecross is very imperfect; for while, as we have seen, its base is nowhere exposed, it is equally impossible to trace the relation of the thick series of strata to the *Lima*- or *Bucklandi*-beds, which make their appearance at another point in the Applecross district.

Besides the sections in the burns at Applecross, there are some other exposures of the Infralias in the district which are of considerable interest. Thus in a stone-pit behind Applecross House a series of beds of limestone of a blue colour, but weathering white and of beautifully oolitic structure, is seen to the depth of about 15 feet. Each floor of limestone is about 1 ft. thick; and they are not separated from one another by partings of shale. The usual fossils are found here, *Ostrea (Terquemia) arietis*, Quenst. sp., being especially abundant and characteristic. The same beds are found dipping seawards at the village, at an angle of from 10° to 12°, and are here traversed by an intrusive sheet of dolerite. These limestones abound with specimens of corals, gasteropods, and oysters.

Between the village and Applecross House masses of sandstone not *in situ* are found, which contain coaly seams and many obscure plant-remains, some of the latter being in a vertical position with respect to the beds.

From the space occupied by the Infralias beds in the great Cliff-section of Raasay (see fig. 2, page 671) it is clear that the strata of this age must have a thickness of from 150 to 200 feet; but the details of their succession can nowhere be distinctly followed. It is evident, however, from an examination of the beds irregularly exposed in the midst of the masses of talus which overwhelm and

obscure all this part of the great cliff-section, that, as in the opposite coast at Applecross, we have marine strata consisting of compact, shelly, and oolitic limestones of a pale blue colour, occasionally abounding with corals, which alternate with thick masses of littoral origin, consisting of shales, sandstones, and grits, with thin and inconstant seams of coal in their midst.

Very interesting for comparison with the section of Infralias strata of Applecross is that exposed along the north shore of Strath between Lussay and Obe Breakish. The beds are only seen in a series of shore-reefs; and their thickness can be estimated only roughly. No estuarine strata are found at this horizon in Skye; but the highest member of the series consists of beds of coarse white sandstone, exhibiting in its false-bedding and other characters clear evidence of having been deposited under estuarine conditions. These sandstones are quite destitute of fossils, and immediately underlie and pass up into the shales and sandstones of the *Bucklandi*- or *Lima*-series.

The Strath section is as follows:—

	feet.
(1) White sandstone, occasionally containing quartz pebbles, and passing into conglomerates. No fossils yet found	30
(2) The Obe-Breakish limestones and shales. One of the upper beds is crowded with <i>Thecosmilia Martini</i> *, E. de From., and forms a veritable coral reef. <i>Ostrea (Terquemia) arietis</i> , <i>O. irregularis</i> , a gigantic <i>Pinna</i> , and many univalves also occur at the same horizon. The limestones are usually compact, but occasionally are very shelly, being almost made up of masses of <i>Ostrea irregularis</i> : they alternate with bands of dark blue shale. These beds are repeated by faults at Broadford (where they are burnt for lime), and appear at many points inland and on the south side of the district of Strath, where they are usually much altered by igneous intrusions, passing into saccharine limestone and ophalcite. The thickness of this set of beds cannot be less than	150
(3) Calcareous sandstones, the surfaces of the beds of which are covered with casts of <i>Cardinia concinna</i>	7 to 8
(4) Another coral reef, formed of <i>Isastræa Murchisonæ</i> , underlain by a compact bed of limestone	3
(5) Greenish and chloritic sandstone, with irregular ferruginous concretions passing down into calcareous grit, and then into hard subcrystalline limestone containing only very obscure traces of shells (<i>Ostrea irregularis</i> , Münt.).	

Only about 9 feet of these beds are exposed; and they lie directly upon the thin representative of the Poikilitic strata of this place (see page 691)†.

* I am indebted to Prof. P. M. Duncan for examining the corals from the west coast of Scotland.

† As one of the most serious and apparently best-circumstantiated charges against the good faith of Dr. Macculloch has been based on a criticism of his description of the strata at this point, it may be as well to examine this charge in detail. We are told that Macculloch commences the line of junction of the Secondary beds and Torridon Sandstone "at the head of the long narrow creek of Obe Breakish, instead of at the village of Lussay, thus colouring as Red Sandstone a space two miles in length, which is actually Lias" (Quart. Journ. Geol. Soc. vol. xiv. 1858, p. 3). But an examination of Macculloch's map, which is taken from a very old and imperfect chart (the best basis he could obtain for his geological observations), will convince any unprejudiced observer that the error

In Ardnamurchan, Mull, and Morvern the Infralias is not exhibited in any good connected sections. The strata of this age appear, indeed, to be of insignificant thickness as compared with their equivalents in Skye, Raasay, and Applecross, and occasionally seem to be on the verge of total disappearance. At the outlier of Beinn-y-Hattan the Infralias appears to have thinned out altogether. There are some isolated deposits in the north of Mull (as at Ru-na-Gal, Calve Islet, and one or two other points) which, though probably of this age, are in too altered a condition for satisfactory determination. At Torosay, and again between Duart House and Duart Castle, the compact limestones and pebbly grits of the Infralias are fairly well exposed, but do not attain any great thickness. The same is the case with some larger exposures on the south side of the island of Mull.

b. *The Lower Lias.*

The strata of this age are very largely developed in the Hebrides and adjacent mainland of Scotland, and constitute a series of deposits (often richly fossiliferous) with a total thickness, in some places, of at least 400 feet. In the most southern part of the area we are describing, the Lower Lias beds most strikingly resemble, both in their mineral and palæontological characters, their equivalents in England; and the great floors of limestone and shale crowded with *Gryphæa arcuata*, Lam., and abounding in *Lima gigantea*, Sow., and Ammonites of the group of the *Arictes*, which are so well exposed at Loch Aline and some other points in the Western Highlands, cannot fail to recall to the mind of the most superficial observer the strata of the same age in this country, namely the well-known *Lima*- or *Bucklandi*-beds.

But when traced further northwards, these strata are found undergoing some remarkable changes in their characters and fossil contents—changes which tell unmistakably of the prevalence of somewhat different conditions as existing in those parts of the Liassic sea.

lies not with Macculloch, but with the map on which he recorded his observations. It is clear that the indentation of the coast where the two formations are made to meet is intended for the harbour of Lussay, and not that of Obe Breakish, as the later writer supposes; and this is shown by the fact that the name of "Lucy" is inserted on the map and mentioned in the text of the work as occurring at the point of junction of the two formations. (Western Isles of Scotland, vol. i. p. 319.) It is greatly to be regretted that a writer in the Journal of this Society, basing his criticisms on this and equally mistaken premises, has permitted himself to make charges of actual fraud against his predecessor. Nothing is easier than this criticism of the old work of a geological pioneer by one who is furnished with accurate modern maps, and has the advantage of the discoveries of later thinkers to guide him. But surely before such a painful charge was made it would have been more fitting that the utmost care should have been taken to avoid misrepresentation, that the fullest consideration should have been given to all the facts of the case, and the amplest allowance made for the difficulties under which Macculloch laboured in the want of even approximately accurate maps, at the early date (1819) at which his researches were carried on.

Thus in Skye and the adjoining districts we find the Lower-Lias limestones and shales exhibiting a tendency to assume a more sandy character, the former passing in many cases into a calcareous grit, and the latter into an argillaceous sandstone; while in some places masses of coarse sandstone and quartzose conglomerate make their appearance in the series; and these certainly seem to indicate the proximity of an ancient shore-line. Nowhere, however, do we find proofs of the prevalence of actual estuarine conditions in the midst of the Lower Lias of the Western Highlands in the same manner in which we have shown such to occur among the equivalent deposits in Sutherland.

The sandstone, grits, and conglomerates intercalated in the Lower Lias series of the Hebrides are usually very unfossiliferous; they, however, occasionally exhibit some evidences of having been accumulated near to land, in the abundant fragments of wood which they contain. The conglomerates are usually made up of well-rounded pebbles of white quartz; and only few and often obscure casts of shells occur in them; these, however, enable us to pronounce with certainty as to the marine origin of the beds which contain them.

In the limestones and shales the fossils, of which individuals are particularly abundant in the Lower Lias of the Western Highlands, serve clearly to indicate the position of the several beds in the geological series. Although, however, individual fossils are so exceedingly abundant, the number of species which can be recorded is by no means so great as would be at first sight anticipated; they are nevertheless amply sufficient for defining the geological horizons of the beds in which they occur.

The great mass of the strata in question clearly belongs to the "*Lima*-beds or Zone of *Ammonites Bucklandi*." This is proved by the remarkable abundance of *Gryphæa arcuata* of the typical form, and by the numerous and fine examples of *Lima gigantea* which occur—and especially by the prevalence of such characteristic arietiform *Ammonites* as *A. Bucklandi*, Sow., *A. Conybeari*, Sow., *A. Kridion*, Hehl, and many others. Many other fossils which occur with these, such as *Nautilus striatus*, Sow., *Pinna Hartmanni*, DeFr., *Lima succincta*, Schloth., and *L. pectinoides*, Sow., *Spiriferina verrucosa*, v. Buch, *S. Walcottii*, Sow., serve to confirm the correctness of the identification of these beds with the well-known deposits of England, Burgundy, and Württemberg.

I have in another work* pointed out the fact that in Lincolnshire the upper part of the *Bucklandi*-beds presents some peculiarities in its fauna which are well worthy of notice and that the deposits on this horizon in that county, which have now become so well known on account of the thick masses of valuable ironstone which they contain, clearly represent that subzone to which Dr. Oppel applied the name of zone of *Ammonites geometricus*, Phill. (an *Ammonite* which is now regarded as identical with *A. semicostatus*, Y. & B.).

* Memoirs of the Geological Survey of England and Wales—"The Geology of Rutland," &c. pp. 42-45.

Precisely the same observation holds good with respect to the Lower Lias strata of the Western Highlands. Here, as in Lincolnshire, we find that the upper part of the "*Lima*-beds," which exhibits some peculiarity in its mineral characters, can also be separated by the presence of certain interesting and well-marked forms of *Ammonites* and other shells from the great mass of strata below.

It seems to me that this partial change of fauna is by no means unworthy of record in the description which I propose to give of the Lower Lias of Scotland. The changes in the characters of the *Ammonites* which characterize this upper portion of the "*Lima*-beds" is especially remarkable and significant; and what is most important of all is, that precisely parallel changes can be traced as making their appearance at the same point in the geological series in Scotland, the North of England, and in Swabia. Thus, while the *Ammonite* forms (I hesitate to call them species) so abundant in the Lower Zone (Zone of *Ammonites Bucklandi*) disappear, a new group of forms, with a most unmistakable family resemblance, takes their place in the Upper Zone (Zone of *Ammonites semicostatus*). Some of these forms, which are distinguished by certain well-marked characters which they have in common, have been already figured and described by Quenstedt; and I hope that a complete series of them, selected from the rich cabinets of the Rev. J. E. Cross, of Appleby, who has done so much towards working out the fine fauna of the Scunthorpe and Froddingham ironstones, will soon be rendered familiar to geologists by the monograph of Dr. Wright now in course of preparation. In the Western Islands we find a number of other minute peculiarities in the fauna of the Upper Zone of the *Lima*-beds, such as we also found in Lincolnshire; in both localities some new forms of Mollusca occur, others disappear, while others again exhibit distinct and characteristic varietal features: thus in both localities *Lima gigantea* assumes a size which it is never known to attain in the Lower beds; and this increased size is accompanied by peculiarities of form and surface-sculpture which are by no means unworthy of notice and study.

While, however, the inferior division of the Lower Lias (that to which Quenstedt applies the term Lias α) is so admirably developed in the Western Highlands, its upper member (Lias β of Quenstedt) appears to be wholly, or almost wholly, unrepresented in the area. In Raasay the dark shales containing the fossils of the zones of *Ammonites armatus* and *A. Jamesoni*, constituting the base of the Middle Lias (Lias γ of Quenstedt), are seen resting directly upon the *semicostatus*-beds. Only in the northern part of the Mull have I succeeded in detecting any trace of the fauna of the Lias β in the Western Highlands. At Tobermory a very fossiliferous stratum occurs (as noticed by Hugh Miller), the palæontological characters of which seem to be of considerable interest, from the fact that in it forms seem to be mingled together which elsewhere characterize the distinct zones of *Ammonites ibex*, *A. Jamesoni*, *A. armatus*, and *A. oxynotus*. The species, however, are for the most part more or less dwarfed in size in this stratum; and as there is no clear section

exposed, specimens from more than a single band may easily be inadvertently mingled together by the collector. It is worthy of note, as I have pointed out in the first paper of this series, that in the Eastern Highlands the Lias β , and especially the zone of *Ammonites oxynotus*, is remarkably well represented.

I may here perhaps remark, while speaking of the identification of the successive zones of life in the Lias, that we have in Scotland some very striking examples of the manner in which a geological horizon, very feebly or not at all represented in one locality, may in another acquire distinctive features, important development, and great thickness; while, on the other hand, a zone, which in one area may consist of thick deposits that appear to be so clearly characterized as to be incapable of ever being by any possibility overlooked or confounded with another, may in a different region be represented by only a thin and inconstant stratum, and, more than this, may lose many of its most distinctive palæontological features, the fossils which elsewhere characterized it being found mingled with those of the beds above and below it.

Thus, though I perfectly agree with Mr. Blake that in Gloucestershire and Yorkshire the Subzone of *Ammonites semicostatus* can scarcely be separated from the Zone of *A. Bucklandi*, yet in Lincolnshire and the Western Highlands such a division is natural, useful, and, I think I may add, indispensable. In the same way the established division of the Lias γ , which is so well developed in Swabia and Yorkshire, might be thought in the Western Highlands to be wholly unnecessary; for scarcely any trace of it is there found.

Nor do these remarks tend to throw the smallest discredit upon the system of classifying strata into palæontological zones, when that system is rightly understood and properly applied. The different quantities of sediment deposited in various portions of the same sea, dependent as that is primarily on the amount of subsidence taking place at a particular time in certain portions of the ocean-bed, will cause the same period of geological time, and the same stage in the history of a fauna, to be very unequally represented by thickness of deposits. The advance of our knowledge may be expected to result in the constant intercalation of new zones of life between the old ones which had before seemed separated by distinct breaks; and by this means some of the imperfections and consequent anomalies of the palæontological record will be removed. In this way we shall be led to entertain more just and correct ideas as to the true succession of life-forms, and have afforded to us fuller materials for investigating the means by which that succession of forms has been brought about.

The most northerly point on the west coast of Scotland at which traces of the Lower-Lias strata have been found is at Tinivulin (Tigh-na-Fiolan), on the north side of Loch Ewe. At this place, however, no Lias strata are exposed *in situ*; but numerous blocks of Lias limestone are found scattered upon the shore, and from these I collected the following fossils:—*Ostrea irregularis*, Münster.; *Gryphæa arcuata*, Lam.; *Pinna Hartmanni*, Ziet. sp.; *Lima succincta*,

Schloth. sp.; *Lima gigantea*, Sow.; and fragments of Echinodermata. It is evident that these have been derived from the Boulder-clay, which is so extensively developed in the peninsula which separates Loch Ewe from Gruinard Bay; and, as pointed out by Professor Nicol, their abundance lends support to the conclusion that beds of this age are now concealed by Glacial drift, or at all events that they were in existence in the immediate neighbourhood at the very recent geological period when those deposits were accumulated. It is scarcely necessary for me to recall attention to the fact of the frequency with which we have to appeal to evidence of the same kind on the east coast of Scotland, where abundant traces of the different members of the Cretaceous and Jurassic systems are found in the Boulder-clay and gravels of the area; though as regards some at least of them it is certain that no trace of the existence of beds *in situ*, which contain the same characteristic fossils, can anywhere be detected.

Among the fragments of limestone derived from the Boulder-clay at Loch Ewe, and which were once collected in sufficient abundance to supply a lime-kiln, there are found representatives of both the Infralias and the Lower Lias. It is probable that the patch of Poikilitic strata let down by faults at Gruinard Bay, and now so greatly obscured by drift-deposits, is, or at all events was at the time of the Glacial period, capped by Rhætic and Liassic strata.

At Applecross, however, there can be no doubt that the *Lima*- or *Bucklandi*-beds of the Lower Lias occur *in situ*. In the year 1872 I was so fortunate as to see some excavations made in the district between the two burns in which the sections of the Infralias beds, already described, were found. These excavations were made in deepening a watercourse, and exposed beds of limestone-rock crowded with *Gryphæa arcuata*, Lam., of the typical form, and containing also many other shells characteristic of the Lias *a*. The great floors of rock crowded with *Gryphæa* were especially striking here.

Among the fossils that I collected at this locality were *Ammonites kridion*, Hehl, *Gryphæa arcuata*, Lam., *Lima gigantea*, Sow., *L. succincta*, Schloth. sp., *L. punctata*, Sow. sp., *Modiola psilonoti*, Quenst., *Avicula sinemuriensis*, D'Orb., *Pecten textorius*, Schloth., *Pecten*, sp., *Unicardium cardioides*, Phill., *Cardinia Listeri*, Sow. sp., *C. crassiuscula*, Sow. sp., *Cardinia*, sp., *Astarte dentilabrum*, Eth. Many of the beds of rock were seen to be completely made up of these and other shells.

Fragments of the same strata are found along the shores of Applecross Bay to the north of the Old-Mill burn. Some of these fragments are crowded with the ossicles of *Pentacrinus*; and in one of them I found a gigantic specimen of *Ammonites Bucklandi*, Sow., with *Ostrea (Terquemia) arietis*, Quenst. sp., attached to it.

So far as the limestones of Applecross Bay are concerned, they are identical in their characters and fossils with the Lower-Lias limestone floors of England. They appear here to alternate with thick beds of shale, which are, however, nowhere well exposed in section.

In the great cliff-section of Raasay lying opposite to Applecross Bay the *Lima*-beds are fairly well exposed, the floors of limestone

standing out from among the intervening crumbling shales in a very striking manner. It is over one of the higher of these floors of limestone that the burn of Hallaig tumbles into the sea, giving rise to a very picturesque waterfall. The thickness of the Lower Lias here cannot be less than 200 feet. At its upper part the sandy argillaceous beds, containing peculiar forms of *Gryphæa arcuata* and the Ammonites which characterize the Zone of *Ammonites semicostatus*, are found; and these are seen to be directly overlain by the shales containing the fossils of the Zone of *Ammonites armatus*.

On the northern slope of Beinn Glamaig in Skye and along the shores of Loch Sligachan the Lower-Lias and Infralias strata are found thrown up at very high angles (from 32° to nearly vertical); they are, however, frequently greatly altered by their contact with the syenite, and their fossils are scarcely recognizable.

The best sections of the Lower Lias in Skye are those exposed along the shore of Broadford Bay, between Obe Breakish to near the village of Broadford, at which latter place the Infralias strata are brought up again by a fault. Here the succession of beds is as follows:—

Above the white sandstone and grit, passing into conglomerate, which we regard as constituting the highest member of the Infralias (though, as they contain no fossils, it may be equally allowable to include them in the Lower Lias), we find a series of dark-coloured, almost black micaceous shales, with only occasional limestone floors, crowded with fossils, which occur both in the shales and limestones, but most abundantly in the latter. The following species were observed:—*Ammonites Bucklandi*, Sow.; *A. Conybeari*, Sow.; *Pleurotomaria similis*, Sow. sp.; *Gryphæa arcuata*, Lam.; *Lima gigantea*, Sow. (normal form); *Cardinia Listeri*, Sow.; *Pecten textorius*, Schloth.; *Pecten*, sp.; *Pinna Hartmanni*, Goldf.; *Unicardium cardioides*, Phil. sp.; *Avicula sinemuriensis*, D'Orb.; and *Spiriferina Walcottii*, Sow. sp. These beds are probably at least 150 feet in thickness.

This series of black, highly micaceous shales is continued upwards by beds of precisely similar mineral character, which, however, contain a slightly different fauna. The typical form of *Gryphæa arcuata*, Lam., with a deep sulcus, is replaced by a variety of the same shell far less conspicuously sulcated. The Ammonites allied to *A. Bucklandi*, Sow., disappear; and in their place we find very abundantly *Ammonites semicostatus*, Y. & B., *A. Sauzeanus*, D'Orb., and several other peculiar forms. The typical form of *Lima gigantea*, Sow., is no longer found; but in its place occurs a variety of greater flatness than the type and of peculiar form. These beds evidently represent the zone of *Ammonites semicostatus*. Their full thickness, however, is not seen at Broadford Bay, as they are faulted against the Infralias strata, which a little to the westward are quarried for lime-burning.

Although the Lower-Lias strata are exposed at many other points both in the interior and along the southern shore of the district of Strath in Skye, yet they nowhere afford good sections. In many places the strata are so altered, as in Strathaird and along the shores of Lochs Eishart and Slapin, that scarcely a fossil can be recognized.

in the beds of indurated black rock (resembling Lydian stone) and the crystalline limestone with opicalcite, into which the shales and limestone are respectively altered. Even here, however, their relation to other rock-masses of known age, and the occurrence of an occasional fossil, enable us to assign the beds in question to their true position in the geological series.

From the above description it will be seen that the Lower Lias of Skye, Raasay, and Applecross appears to differ from the normal type by the smaller development of the limestone-floors and the prominence of the intervening masses of black micaceous shale. The more northern area of the Lower Lias is cut off by a considerable interval, in which no traces of the formation are found, from the districts of Ardnamurchan, Morvern, and Mull, in which we find exposures of the Lower Lias assuming characters much more nearly in conformity with those of the typical beds in England. In the southern district of the Western Islands the beds of limestone are much more fully developed than in the northern area; and the English geologist is everywhere struck by the very close resemblance of the oft-repeated limestone-floors, with only thin shaly partings between them, to the strata of equivalent age in the southern part of this island.

In the peninsula of Ardnamurchan the Lower-Lias strata are met with at various points, but good exposures of them occur only in the sea-cliffs. On the north side of the peninsula the cliffs at Surdil exhibit great masses of limestone alternating with shale, and crowded with *Gryphæa arcuata*, Lam., and other fossils. These beds rest on the compact limestones and calcareous grit of the Infralias, which in turn repose on the representative of the Poikilitic. The upper portions of the Lower-Lias strata at Surdil have undergone great metamorphism, being traversed in all directions by innumerable dykes; in this part of the series the limestones become highly crystalline, and every trace of fossils is obliterated.

On the south side of the peninsula of Ardnamurchan the Lower-Lias limestones are well exposed in the reefs below the picturesque ruins of Mingary Castle, and for a considerable distance along the shore between Kilhoan and Sron More. The beds are in places considerably interfered with by masses of basalt, forming both intrusive sheets and dykes. The lowest beds of the Lower Lias here, which are seen directly reposing on the compact limestones of the Infralias, consist of limestones of somewhat sandy character containing numerous specimens of *Gryphæa arcuata*, Lam., of the typical form. Beds almost made up of the ossicles of *Pentacrinus* occur here.

The highest beds of the Lower Lias, which are greatly altered on the north side of the Ardnamurchan peninsula, are, on the south side, admirably exposed; and the alteration which they have undergone is small in extent and of merely local character, being confined to the immediate proximity of the masses of intrusive rock. We here find, too, clear proofs of the presence of the Subzone of *Ammonites semicostatus*. It is represented by a thick mass of dark micaceous shale, with only occasional limestone bands, very similar

in character to the equivalent strata in Broadford Bay, Skye. In these beds I found the following fossils, which are tolerably abundant:—*Ammonites Brookii*, Quenst. (non Sow.); *A. semicostatus*, Y. & B.; *A. falcaries*, Quenst.; *A. Sauzeanus*, d'Orb.; *Belemnites acutus*, Mill.; and the abnormal form of *Gryphæa arcuata*, Lam., which is characteristic of this horizon in the Lower-Lias series.

In the district of Morvern the Lower-Lias strata are especially well developed, and are remarkable alike for the abundance of their fossils and the striking agreement in character with the equivalent beds in England.

Nowhere, indeed, can the Lower Lias of the Western Highlands be studied to greater advantage than on the shores of "green Loch Aline," which opens on the eastern side of the Sound of Mull. On the western side of the Loch, a few hundred yards above the village, the floors of Lower-Lias limestone form reefs on the shore which are uncovered at low water; and from these the fossils, beautifully weathered out, can be collected in the greatest abundance and perfection. The beds have a gentle dip to the south, and are seen to be covered unconformably by the strata of Upper-Greensand age, which are so well exhibited here. Further up the Loch, and on the same side of it, there are two old quarries where the stone has been worked for lime-burning; and at various points in the wooded cliff and along the shelving shore exposed at low-water the same beds can be traced.

Crossing to the opposite or eastern side of the Loch we find, besides numerous small exposures, a magnificent section, probably not less than 70 or 80 feet in depth, showing admirably the alternating floors of Lower-Lias limestone and shale crowded with fossils. This is certainly one of the finest and most interesting sections of the Lias in the Western Highlands; the number and beauty of preservation of the organic remains are surprising, and are sufficiently remarkable, indeed, to arrest the attention even of an observer accustomed to the most admirable and fossiliferous exposures of the English Lias.

Near Ardtornish Point, outside Loch Aline, at the part of the shore below the famous Castle which stretches furthest to the southwards, beds of limestone, crowded with the typical forms of *Gryphæa arcuata*, Lam., and *Lima gigantea*, Sow., are seen in the reefs exposed at low water. Here I collected several very large specimens of *Ammonites Bucklandi*, Sow. Still further to the east, where the grand basaltic cliffs of Ardtornish commence, the *Bucklandi*-beds, crowded with the same characteristic fossils, are again exposed on the shore near the keeper's lodge; and a ruined lime-kiln close by indicates that the beds were once burnt for lime at this point.

Inland, around the shores of Loch Arienas (L. Conich), the Lias strata are nowhere exposed except in the remarkable outlier of Beinn-y-Hattan. Over a great part of this area there is an unconformable overlap of the Upper-Greensand and overlying Cretaceous strata, the Lias strata having been removed by denudation before the deposition of the Cretaceous rocks. The section at Beinn-y-

Hattan is especially interesting, as exhibiting a last vestige of the usually grandly developed Lower Lias of this area. Only a few feet of Lias strata are here found cropping out from beneath the unconformably superposed Cretaceous; but the age of the beds is, fortunately, placed beyond question by the discovery of the following fossils—*Gryphæa arcuata*, Lam., *Unicardium cardioides*, Phill. sp., *Cardinia Listeri*, Sow. sp., *Lima pectinoides*, Sow. sp., *Pecten*, sp., and *Pentacrinus*, sp. The strata containing these fossils exhibit all the usual characters of the Lower Lias, consisting of alternating limestones and shales; they appear to rest directly upon the Poikilitic; and certainly the Infralias, if present at all, must be reduced to insignificant proportions.

As indicating the richness of the fauna of the Lower-Lias strata around the shores of Loch Aline, we may cite the following list of fossils found there:—

Vertebræ of <i>Ichthyosaurus</i> .	<i>Lima gigantea</i> , Sow. sp. }	both very large
<i>Ammonites Bucklandi</i> , Sow., very large.	— <i>succinata</i> , Schl. sp. }	and abundant.
— <i>multicostatus</i> , Sow.	— <i>pectinoides</i> , Sow. sp.	
— <i>Conybeari</i> , Sow.	<i>Avicula sinemuriensis</i> , D'Orb.	
— <i>kridion</i> , Hehl.	<i>Pecten textorius</i> , Schloth.	
— <i>spinaries</i> , Quenst.	— <i>Hehlii</i> , D'Orb.	
— <i>spiratissimus</i> , Quenst.	—, sp.	[(rare).]
—, sp.	<i>Ostrea</i> (<i>Terquemia</i>) <i>arietis</i> , Quenst. sp.	
<i>Nautilus striatus</i> , Sow.	<i>Ostrea</i> , sp.	
<i>Phasianella</i> (?), sp.	<i>Gryphæa arcuata</i> , Lam., typical form	
<i>Cardinia Listeri</i> , Sow. sp.	in enormous abundance.	
<i>Myacites liasinus</i> , Röm.	<i>Serpula</i> , sp.	
— <i>alduinensis</i> ?	Spines of <i>Acrosalenia</i> .	
<i>Pholadomya glabra</i> , Ag.	<i>Pentacrinus tuberculatus</i> , Mill.	
<i>Astarte dentilabrum</i> , Eth.	— <i>briareus</i> , Mil.	
<i>Pinna Hartmanni</i> , Goldf.	Large <i>Fucoid</i> (?) markings.	

At one or two points in the vicinity of Loch Aline the ordinary *Bucklandi*-beds, which, as we have seen, are so well developed, are seen to be covered by thick masses of dark micaceous shale; and in these I have detected, at more than one locality in the district, the fossils which characterize the Subzone of *Ammonites semicostatus*. The beds on this horizon, however, are nowhere well exposed in good sections in the district in question; but, taken altogether, the exposures of the Lower Lias in the district of Morvern are without a parallel, whether we regard the clearness of the sections of the strata or the variety and admirable preservation of the fossils which they yield, in the whole of the Western Highlands.

In the island of Mull, on the other hand, the sections of the Lower Lias do not present much that is worthy of note. On the shores of the Sound of Mull at Craignure (Auchenacroish), opposite to Ard-tornish, the Lower-Lias limestones are seen on the shore, but are often converted (in consequence of their proximity to igneous masses) into saccharoid limestone, in which, however, the forms of *Gryphæa arcuata*, Lam., and *Lima gigantea*, Sow., can sometimes be distinguished. The metamorphism of the beds is found to diminish as we follow the series upwards; and the higher parts of the *Buck-*

landi-beds here are seen resuming their normal characters. Further east, towards Duart House, they are found to be covered by thick masses of indurated micaceous shales in which fossils are rare. I, however, succeeded in detecting in them several of the forms of Ammonite so characteristic of the Subzone of *Ammonites semicostatus*.

The Lower Lias reappears on the south side of the Island of Mull. At Carsaig the well-marked strata of the Zones of *Ammonites semicostatus* and *A. Bucklandi* are seen cropping out from beneath the Pabba Shales, which are so finely developed at this point. The older set of beds, however, is much disturbed and altered by igneous intrusions; and as we trace down the series in the direction of Loch Buy, we find the strata completely and somewhat abruptly cut off by the intrusion of volcanic masses of Miocene age. I succeeded in detecting here some of the characteristic Ammonites of both the divisions of the Lower Lias; and specimens of *Ammonites Bucklandi*, Sow., have been found which attained to a very great size. I received very great assistance during my studies of this part of the Isle of Mull from Mr. A. Maclean, of Carsaig.

In the precipitous cliffs stretching to the eastward of Loch Buy the Lower-Lias strata are probably represented. But here all the stratified masses are in such close proximity to the great igneous centre of the Mull volcano, and have in consequence undergone such intense metamorphism, that it is almost hopeless to seek to identify the several formations, their fossils having been in almost every instance completely obliterated.

c. *The Middle Lias.*

This division of the geological series is most admirably developed in the Western Highlands. It consists of two well-marked members, which can everywhere throughout the district be fairly well distinguished, though they are not separated by any sharp line of division, either physical or palæontological. The lower of these members of the Middle Lias consists of sandy shales, and it may be conveniently denominated (after the name of the island in which it is very beautifully exposed) "the Pabba Series." The upper member of the Middle Lias, in the Western Highlands, consists of a great thickness of calcareous sandstones, which, from the island in which they are equally well developed, we may call "the Scalpa Series." The palæontological evidence happily leaves us in no doubt as to the geological horizons to which these two series ought severally to be referred; for each of them contains an abundant and very distinctive fauna. By the study of these faunas it becomes clear that the Pabba Series represents Quenstedt's Lias γ , the Zones of *Ammonites Jamesoni*, *A. ibex*, and *A. Davöi* of Dr. Oppel; while the Scalpa Series is the equivalent of the Lias δ , the Zones of *Ammonites margaritatus* and *A. spinatus* of the former author.

The Pabba Shales retain remarkably uniform characters over a wide area, and consist of more or less sandy and very micaceous

shales, with many limestone nodules. At many points, where exposed in the cliffs, the beds of this series are apt to be concealed by a talus of fallen blocks, which have descended from the overlying harder beds of the Scalpa Series. But at Hallaig in Raasay in the island of Pabba, and at Tobermory and Carsaig in Mull, there is no difficulty in studying the beds of the Pabba Series and of collecting their fossils, which, at all these localities, are singularly abundant, and sometimes in a fine state of preservation. The greater portion of the strata of the Pabba Series must clearly be referred to the Zone of *Ammonites Jamesoni*, which is perhaps nowhere represented by beds of such great thickness and highly fossiliferous character. At the base are some strata in which *Ammonites* of the group of the *Armati* abound; and these may be regarded as representing the Subzone of *Ammonites armatus* of Dr. Oppel. In their upper part, and where the sandy shales of the Pabba Series graduate into the calcareous beds of the Scalpa Series, bands of limestone nodules appear in the midst of the shales; and it is by the gradual increase in frequency of these nodular calcareous bands that the Middle-Lias beds gradually lose their argillaceous character, and pass into calcareo-siliceous rocks. Now a study of the fossils of this intermediate series of beds, which is well seen both in Raasay and Skye, shows that they represent the Zone of *Ammonites capricornis* of English geologists, and probably the Zones of *Ammonites Davöi* and *Am. ibei* of Continental authors.

The masses of calcareous sandstones constituting "the Scalpa Series" are usually highly micaceous, like the Pabba beds below; in some places they assume ferruginous, and in others argillaceous characters, but generally appear in the form of sandy limestones and calcareous grits of a grey or yellow tint. Their fossils are unmistakably those of the Zones of *Am. margaritatus* and *Am. spinatus*, the two zones being perhaps not very distinctly separated in this district. There is certainly, however, no part of the British Islands where this portion of the Middle-Lias formation is found to be represented by so vast a thickness of strata. Although the mineral characters are tolerably uniform throughout the whole of the Scalpa Series, while many of the species of fossils range from the top to the bottom of it, yet a distinction of the two zones to which its beds belong, can be made out by the prevalence of *Ammonites spinatus*, Brug., and *Gryphæa gigantea*, Sow., in its upper beds, and of the varieties of *Ammonites margaritatus*, de Montf., with *Gryphæa cymbium*, Lam., in the lower beds. Near the Sound of Scalpa, and in Strathaird, the Middle-Lias strata, though clearly recognizable by their position, have, in consequence of their proximity to the great volcanic centre of Skye, undergone such changes that many of their mineral characters have disappeared, and almost all traces of their fossils have been obliterated. Intersected as they are by multitudinous dykes, and changed for the most part into brittle quartzites and burnt shales resembling Lydian stone, it is only here and there that one is fortunate enough to detect the cast or impression of a fossil upon which to base an opinion concerning the age of the strata which

contain them. Precisely the same is true of the Middle-Lias strata of Ardnamurchan, which have suffered in an equal degree with those of the southern part of Skye from their proximity to the central axis of a great volcano.

In Mull, however, the Middle-Lias beds are exposed in an unaltered condition both at Tobermory, on the north side of the island, and at Carsaig, on its south side. At both localities the beds of the Pabba Series exhibit their usual characters, while the overlying Scalpa strata appear in a somewhat different condition from that which they assume in the more northern area. In Mull the Scalpa beds are less calcareous, and consist of greenish and yellow sandstones containing far fewer fossils than their equivalent beds to the northward. In their upper part they graduate upwards into white sandstones and grits, often containing much carbonaceous matter. These changes are suggestive of the prevalence of more littoral, sometimes perhaps even passing into estuarine, conditions in the southern part of the area in question.

The most northern localities at which the strata of Middle-Lias age have been detected are on the eastern shores of Trotternish, in Skye, and the great cliff-sections of Raasay. At both these localities their presence was pointed out by Sir Roderick Murchison, who, in drawing his sections, has fallen into some confusion through mistaking parts of the Middle Lias for Inferior Oolite, the two formations being represented in this area by beds of remarkably similar mineral character. But along the shores at Prince Charles's Cave, and again on the south side of Portree Harbour, as well as in the great mural precipices of Tor Inivaig, we find numerous exposures of both the members of the Middle-Lias series. Owing to the numerous slipped masses and the inaccessibility of these precipitous cliffs, however, it is very difficult to obtain satisfactory continuous sections; and the difficulty is increased by the fact that the stratified rocks are often broken up and interrupted by intrusive sheets of basalt, and by the circumstance that their strata are subject to rapid and frequent variations in mineral characters within very short horizontal distances. This will be well seen by comparing the several fragmentary sections adduced by the late Dr. Bryce and Professor Tate (see *Quart. Journ. Geol. Soc.* vol. xxix. p. 317), which nevertheless serve to give a good general idea of the nature and mode of succession of the beds of this part of the Hebridean Lias. Prof. Tate has done good service to Scottish geology by recording the numerous species of fossils occurring in these strata on the east coast of Skye.

On the east side of the island of Raasay the Middle-Lias strata are magnificently developed, the total thickness of the deposits of this age being there probably not less than 500 feet. By the action of the great fault the beds are repeated so that the higher strata (the Scalpa Series) are found extending along the shore for a considerable distance on its south or downthrow side. The fossils are here very numerous alike in the sandy limestones, the calcareous shales (which often contain great concretionary nodules of limestone), and the

ferruginous rock: in the latter they are in the condition of hollow casts. Among the most common fossils here are *Belemnites brevisformis*, Ziet., *Ammonites margaritatus*, de Montf., *A. Englehardti*, D'Orb., *Pecten æquivalvis*, Sow., *P. sublævis*, Phil., and *P. liasinus*, Nyst, *Gryphæa cymbium*, Lam., and *G. gigantea*, Lam., *Rhynchonella tetrahedra*, Sow., and *R. acuta*, Sow., *Spiriferina Walcottii*, Sow. sp., and *S. rostrata*, Schloth. sp.; but nearly all the well-known forms of the English Middle Lias may be found by a diligent collector of the fossils, together with a few species which appear to be peculiar to this area. Some of the beds appear to be almost made up of the shells of *Gryphæa* and *Pecten*, while calcareous concretions, crowded with *Rhynchonellæ*, are very common.

The underlying argillaceous beds (the Pabba Shales) are not so well exposed in the cliff-section, owing to the foundering of masses of the superincumbent harder beds. At the Moor of Hallaig, however, these micaceous clays cover a considerable area, and are traversed by innumerable dykes of basalt. These having been in many cases removed by atmospheric disintegration, have caused the moor to be furrowed in all directions by a series of deep trenches, which prove very dangerous to the unwary traveller. In the sides of these trenches, and in the watercourses, numerous fossils of the Pabba Shales can be found; and a list of the species from this district has been given by Professor Tate (see Quart. Journ. Geol. Soc. vol. xxix. p. 342). Both *Ammonites Jamesoni*, Sow., and its accompanying species, and *A. armatus*, Sow., with the forms usually associated with it, occur at Hallaig. The species of fossils and characters of the beds are identical with those seen at the island of Pabba.

At several other points in Raasay strata of Middle-Lias age may be detected. Thus, near Suishnish Point the Pabba Shales are seen traversed by numerous trap-dykes. Here fossils are numerous, and of the same species as at Hallaig and Pabba. Among the most numerous forms were *Belemnites paxillosus*, Schloth., *Ammonites brevispina*, Sow. (sometimes of large size), *Gryphæa obliqua*, Sow., *Pecten æquivalvis*, Sow., *P. sublævis*, Phil., and *P. liasinus*, Nyst, *Pinna folium*, Y. & B., *Hippopodium ponderosum*, Sow., and *Avicula inæquivalvis*, Sow.

The existence of inland developments of the Pabba strata is indicated by the characteristic fossils which are sometimes found; but no useful sections occur at points other than those already referred to in the island of Raasay. The exposure of the Scalpa beds in the great cliffs between Fearn and Leac is particularly fine; but, on account of the inaccessibility of the cliffs, a good continuous section cannot be obtained.

The manner in which, owing to the action of a great fault, the Scalpa beds are found lying against the Torridon Sandstones in the island of Scalpa, has been already illustrated (see page 673, fig. 4). The upper part of the Lias series here abounds with fossils, which, however, are not very well preserved. Owing to the residence for some time in this island of a former student of the Royal School of Mines (Mr. A. Grant), I was enabled to obtain a considerable number

of fossils from this locality. As they serve very well to illustrate the general fauna of the Scalpa beds, which here display their typical mineral characters, consisting of more or less calcareous sandstones and sandy shales, I have appended a list of the most abundant species; hitherto only some two or three species had been recorded from the island in question:—

Belemnites elongatus, *Mill.*
Ammonites spinatus, *Brug.*
 — *margaritatus*, *De Montf.*
 — —, varieties.
Cryptæna expansa, *Sow. sp.*
Pholadomya ambigua, *Sow.*
Avicula inæquivalvis, *Sow.*
Lima Hermannii, *Ziet.*
 — *acuticosta*, *Sow. sp.*
Pecten æquivalvis, *Sow.*
 — *sublævis*, *Phil.*
 — *liasinus*, *Nyst.*
 — —, *sp.*

Plicatula spinosa, *Sow.*
 — *læviuscula*, *D' Orb.*
Gryphæa cymbium, *Lam.*
 — *gigantea*, *Sow.*
Rhynchonella tetrahedra, *Sow. sp.*
 — *bidens*, *Phil. sp.*
 — *acuta*, *Sow.*
 — —, *sp.*
Terebratula resupinata, *Sow.*
 — *punctata*, *Sow.*
Pentacrinus robustus, *Wr.*
 — —, *sp.*

The exposure of the Middle-Lias strata in the little island of Pabba has often been described, and is justly celebrated on account of the abundance of its fossils and the perfect condition in which they are sometimes obtained. The dark brown micaceous shales which compose the whole of this flat grass-covered island are well exposed in the long shore-reefs, which are traversed by numerous basaltic dykes that sometimes rise like great walls above the mouldered masses of clay. Hugh Miller, in his graphic sketches of the geological features of this district, was the first, after Macculloch, to direct general attention to this rich storehouse of fossil remains; and, acting upon his suggestion, Professor A. Geikie made a considerable collection of the fossil forms occurring there, which were carefully catalogued (the new species being described, but not figured) by Dr. T. Wright*.

Although the Middle-Lias strata certainly occur at a number of points in the district of Strath, in Skye, as under Beinn-na-Cailleach in the north, and at Strathaird in the south, yet the proximity of great igneous masses has resulted in such a vast amount of local metamorphism that the fossils are almost everywhere obliterated, and the characters and succession of the beds rendered exceedingly obscure.

Precisely the same remark applies to the exposures of Middle-Lias strata in the district of Ardnamurchan, the next point southward from Skye at which they appear. Here the rocks of this age are usually metamorphosed so that no fossils are recognizable; but the order of succession of the strata, and an occasional fossil, enable us to establish the fact that certain highly indurated shales and impure limestones (the latter reduced to a highly crystalline condition through the plexus of dykes by which they are intersected) really belong to this part of the geological series.

Thus, on the east of Kilhoan Bay we find sandy micaceous blue

* *Quart. Journ. Geol. Soc.* vol. xiv. (1858), p. 24.

shales passing into hard sandstones and occasionally into impure subcrystalline limestones. In these beds there can be made out in places traces of Belemnites with Ammonites (too imperfect for specific identification), numerous Pectens of large size, and *Gryphæa obliqua*, Goldf. These certainly represent some part of the Middle-Lias series. Traced a little further to the west, the fossils altogether disappear, and the rocks pass into the so-called Lydian stone of Macculloch (burnt shale), quartzite, and crystalline limestone. There are few localities better adapted than the one in question for the study of the series of changes, and especially of the gradual obliteration of all traces of fossils in rocks, through contact metamorphism. There can be little doubt that the Middle-Lias beds are of considerable thickness in Ardnamurchan.

At Bloody Bay, on the north side of the Island of Mull, beds of sandstone of a bright red colour are found, which have been quarried for building the lighthouse of Ru-na-Gal near at hand. The eroded surface of these beds is seen to be directly covered by the Miocene basaltic lavas. The most probable horizon to which to refer the beds in question, which have not yielded a trace of fossil remains, would appear to be that of the Torridon Sandstone, in which case the locality is interesting as exhibiting the most southern exposure of strata of that series. The peculiar sections at Tobermory, now about to be mentioned, however, cause me to entertain some doubt as to whether these red sandstones may not really be an altered condition of the Scalpa Series. At present the question of the age of these beds (as is not unfrequently the case with isolated patches of unfossiliferous strata in the Hebrides) must be regarded as still an open one.

At Tobermory there appear, from underneath the basalts, beds of sandstone of a deep red colour, and dark-coloured micaceous shales. The former beds have been quarried on a small scale for building-purposes; the latter extend over the tide-way and are seen at low water; they have also been found in digging wells. These beds, like those of Pabba, seem to have been first pointed out to geologists by Hugh Miller, who, judging from mineral characters alone, regarded the red sandstones as the "Old Red." I have found in these red sandstones, however, specimens of *Gryphæa obliqua*, Goldf., though fossils are certainly very rare in them; and thus it is rendered manifest that we have here some arenaceous beds in an altered condition intercalated in the Middle Lias series. It is possible that the strata already mentioned as occurring at Bloody Bay, with others at Calve Islet and on the shores of Mull, two or three miles to the southward, none of which have yielded fossils, may all be of the same age.

The dark micaceous shales of Tobermory, which are exposed only in a small opening at the mill, as described by Hugh Miller, yielded very numerous fossils, though not in a very good state of preservation. Mr. Hugh Miller, F.G.S., who has perseveringly explored the rocks and studied the localities which his father's graphic pen has rendered famous, has made a very considerable collection of fossils from this locality; and these he has most obligingly placed at my

disposal. From Mr. Miller's and my own collections I am able to give the accompanying list, which, although by no means exhaustive, will suffice to prove the beds in question to be without doubt the Pabba Shales. The fossils here are very numerous, but in a very bad state of preservation, and often very difficult of determination.

List of Fossils from the Pabba Shales at Tobermory.

Belemnites elongatus, <i>Mill.</i>	Cucullæa Münsteri, <i>Goldf.</i>
— acutus, <i>Mill.</i>	Myoconcha oxynota, <i>Quenst.</i>
Ammonites oxynotus, <i>Quenst.</i>	— scabra, <i>Terg. et Piette.</i>
— raricostatus, <i>Ziet.</i>	Arca elongata.
— densinodus, <i>Quenst.</i>	Mytilus hippocampus, <i>Y. & B.</i>
— Buignieri, <i>D'Orb.</i>	Limea acuticosta, <i>Goldf.</i>
— ibex, <i>Quenst.</i>	Lima punctata, <i>Sow.</i>
— Valdani, <i>D'Orb.</i>	— succineta, <i>Schloth.</i>
Scalaria liassica, <i>Quenst.</i>	Pinna folium, <i>Y. & B.</i>
Turbo foveolatus, <i>Ziet.</i>	Plicatula spinosa, <i>Sow.</i>
Pholadomya ambigua, <i>Sow.</i>	— lævigata, <i>D'Orb.</i>
Unicardium cardioides, <i>Phill. sp.</i>	Pecten sublævis, <i>Phill.</i>
Lyonsia unioides, <i>Röm.</i>	— priscus, <i>Schloth.</i>
— scottica, <i>Wr. sp.</i>	— tumidus, <i>Ziet.</i>
Leda complanata, <i>Phil. sp.</i>	Gryphæa obliqua, <i>Goldf.</i>
— subovalis, <i>Goldf.</i>	

The general association of fossils at Tobermory appears to prove that the horizon represented there is the base of the Pabba shales; and we have apparently an admixture of Lower- and Middle-Lias species. This is the only locality on the west coast of Scotland at which the peculiar fossils of the Zone of *Ammonites oxynotus* have been found; and here they occur mingled with others that belong to higher horizons. On the east coast of Scotland, as we have already shown, the Zone of *Am. oxynotus* is very distinct and well developed.

At several points about Loch Aline and Ardtornish the Middle Lias beds are certainly present, but, being covered with vegetation, exhibit no section.

On the opposite shores of the Sound of Mull the dark black shales of the Pabba Series make their appearance below Duart House, but are here, as a rule, remarkably unfossiliferous, though of considerable thickness. The overlying Scalpa beds are also present, but exhibit very different mineral characters from those by which they are distinguished in their northern exposures. In Mull the Scalpa beds are represented by greenish sandstones, with but little calcareous matter, and very poor in fossils. The abundance of carbonaceous matter in some of these beds, coupled with the presence of false-bedding, ripple-markings, worm-tracts, and fucoid impressions, points to the conclusion that they originated in water of considerably less depth than their northern equivalents.

Some greatly altered rocks at Loch Spelve, on the south-east of Mull, have yielded me *Pecten sublævis*, *Phill.*, and one or two other Middle-Lias fossils; and it is probable that the same formation is represented among the intensely altered strata of the south coast of this island.

At Carsaig strata in a less altered condition, fortunately, make their appearance. Above the Lower-Lias strata of this locality, we find

the Pabba Shales well-exposed in the flats uncovered at low water; and the sandy and littoral faciès of the Scalpa Series is exhibited in the cliffs, especially at the fine waterfall behind Carsaig House and in the quarries which have recently been opened for the new buildings. The latter beds have also been quarried at some places to the westward, and make their appearance at many points in the cliffs, especially about the Nun's Cave, which has been hollowed out in them.

The fossils of the Pabba Shales of Carsaig were collected with much perseverance by the late Captain Bedford, while engaged in preparing the Admiralty Charts of these inaccessible shores. A list of species drawn up from his collections by Messrs. Davidson and Etheridge will be found in the *Geologist*, vol. v. p. 443.

The sandy representative of the Scalpa beds is, as at Duart, rather poor in fossils—*Pecten sublaevis*, Phill., and *Gryphæa cymbium*, Lam., being, indeed, the only common forms. The rock here seems to be capable of furnishing a useful freestone. It was quarried for the famous edifices of Iona; and fresh supplies have recently been obtained for the repairs of those buildings. But for the inaccessibility of the rocky shores on which they are exposed, it is probable, indeed, that the beds would be extensively worked for building-purposes.

The exposures of the Middle Lias near Carsaig are of much interest, furnishing us, as they do, with the most southern exposure of the beds of that age in the Hebrides. Their equivalents next make their appearance as we pass southwards in the north of Ireland and in the outlier on the borders of Cheshire and Shropshire, though it is impossible to doubt that beds of this age have originally existed, and have been removed, by denudation, over a great part of the intervening area.

d. *The Upper Lias.*

As the beds of this age (owing to the faults by which the series of strata is there broken up) are nowhere exhibited in the Eastern Highlands, it is of particular interest to find them so clearly displayed, and presenting such an unmistakable and characteristic fauna, in the Hebrides. Lying, as they do, between the hard masses of the Scalpa Series below, and the Inferior Oolite above, the Upper Lias beds are almost everywhere covered by heavy taluses of fallen blocks; and it is not to be wondered at that Murchison, failing to recognize their existence, massed the strata of Middle Lias with those of the Inferior Oolite. To Messrs. Bryce and Tate we are indebted for first pointing out the existence of the Upper Lias formation in Skye—though even they appear to have failed to detect proof of its existence in the neighbouring island of Raasay. During my study of the district, I have found many evidences of the presence of this part of the Lias series, and have examined some interesting sections of its beds in both these islands, succeeding also in tracing deposits belonging to this geological horizon as far southwards as Ardnamurchan. In this last-mentioned district, however, the strata in question have suffered greatly from metamorphic action.

The Upper-Lias formation in the Western Highlands remarkably resembles both in the character and succession of its beds and its fossil remains the equivalent strata in England. In both districts we find the formation made up of laminated blue clays, containing argillaceous nodules, with much pyrites and jet in certain of its beds. This parallelism of the Scottish Upper Lias with that of England comes out in an even more striking manner when we study the distribution of organic remains in their several members. Thus, in the upper part of both we find an abundance of *Ammonites communis*, Sow., and similar forms, associated with *Posidonomya Bronni*, Voltz, and *Belemnites*, while at the base strata characterized by the abundance of *Ammonites serpentinus*, Rein., *Am. radians*, Rein., *Am. elegans*, Sow., and many other species of the group of the *Falciiferi*, are equally distinctive of the beds.

The thickness of the Upper-Lias series in the Western Highlands is not very great. It averages perhaps from 75 to 80 feet, and occasionally, but rarely, reaches 100 feet. On the other hand, it is sometimes perhaps as little as 60 feet thick. Mr. Tate gives a measured section taken on the east side of Portree Harbour, which shows the Upper Lias as only 15 feet 7 inches thick; but as the section here is rendered somewhat difficult of interpretation through the numerous slipped masses, I have little doubt that the beds enumerated do not comprise the whole thickness of the formation at this point.

To Dr. Bryce and Professor Tate we are, as already mentioned, indebted for first pointing out the existence of the Upper Lias in Skye; but it seems to me, from a reexamination of their sections, that they have almost everywhere underestimated its thickness, having been betrayed into this mistake by the slipped condition of the beds in the great mural precipices and the interruption and confusion produced in the beds by the intrusive sheets of dolerite which are so numerous at the localities where the formation is exposed.

In Raasay the same strata are present, as I have been able to satisfy myself on several different occasions. Though certainly from 80 to 100 feet in thickness, they nowhere exhibit good sections, being almost always buried under talus from the beds above and also grass-covered.

Between Leac and Fearn, however, above the great development of the Scalpa Series, they consist of black laminated highly micaceous and ferruginous shales with *Belemnites Voltzii*, many *Ammonites* of the group of the *Falciiferi*, such as *A. serpentinus*, Rein., *A. falciifer*, Sow., and *A. radians*, Rein., but all small and crushed, and some other shells. The same beds make their appearance, but even more obscurely, further to the north, in the precipices of Serepidale.

The Upper-Lias strata are certainly present in the district of Strath in Skye, and most probably also in Ardnamurchan; but in both these areas the beds are so greatly metamorphosed as to be only recognizable by their relations to the Middle Lias and Inferior Oolite respectively. In Mull they have nowhere been detected, the older strata being everywhere overlapped by the Cretaceous rocks.

c. *The Lower Oolite.*

The series of strata representing this formation in the Western Highlands is of very considerable thickness and importance. Rocks of this age must, indeed, have originally had a very wide distribution; for traces of them are found at various points, from the Shiant Isles in the north to Ardnamurchan in the south. The best exposures of their strata, however, are those which occur in the Islands of Skye and Raasay, in the sections so well described by Sir Roderick Murchison, and afterwards in greater detail by the late Dr. Bryce and Mr. Tate.

The Inferior Oolite, where best developed in the Western Isles, has a thickness of probably not less than 400 feet. An exact estimate of the dimensions of the whole formation and of the proportions of its several members is, however, rendered difficult owing to the manner in which the numerous intrusive sheets of Tertiary dolerite are interspersed through the series, and interrupt the continuity even of its best sections. The formation may be defined as consisting of the following members, proceeding from above downwards:—

	feet.
I. Limestones, almost wholly made up of comminuted shells, and resembling in their mineral characters the English Cornbrash and Forest Marble, with which formations they were identified by Sir Roderick Murchison.....	45
II. Beds of white sandstone, with some subordinate shaly bands, the whole containing much carbonaceous matter and some plant-remains, including both Ferns and Cycads	60
III. Alternating beds of sandstone and shale, the sandstone being usually calciferous, and containing great spherical concretions, and sometimes passing into shelly limestones. Marine fossils occur in these beds, but are by no means common, except in the highest of them, which abounds in Belemnites of several species. Ferns, Cycads, wood, and plant-remains of various kinds occur throughout the whole series	160
IV. Sandy micaceous shales, alternating with calciferous sandstones, the latter containing numerous spherical concretions and exhibiting mamillated surfaces. There are also some bands of shelly limestone in the series. Fossils, all of which are of marine forms, abound in these beds.....	120

With respect to the correlation of these different members of the Lower Oolite, it may be remarked that the division I., although made up of fragments of shells, seldom contains specimens in a sufficiently perfect state of preservation to permit of their specific determination. No Cephalopods have been found in this part of the series; and the few species of Lamellibranchiata and Brachiopoda which it has yielded, though all of Lower Oolite age, are not sufficient to enable us to state absolutely whether the bed should be regarded as belonging to the Great or to the Inferior Oolite series.

The division II. is probably of estuarine origin, and there is no direct palæontological evidence concerning its exact position in the geological series. It is clear, however, that it is on the same horizon with one or other of the Lower-Oolite Estuarine series of the English Midland Counties or of Yorkshire.

The division III. yields a considerable number of fossils, Belemnites of several species, *B. giganteus*, Schloth., and *B. aalensis*, Voltz, especially, being particularly abundant; and with these there occur specimens of *Ammonites Humphriesianus*, Sow., and of several of its varieties, such as *A. Blagdeni*, Sow., and *A. coronatus*, Ziet. A few other marine fossils, with some plant-remains, also occur at this horizon, which clearly represents the Zone of *Ammonites Humphriesianus*.

The division IV. is much richer in fossils than any of the higher members of the Lower Oolite, *Ammonites Murchisonæ*, Sow. (first described from a specimen obtained on the coast of Trotternish, near the islet of Holm), is particularly abundant throughout the division; and with the normal type of this species there occur many of the varietal forms, such as *Am. corrugatus*, Sow., *Am. leviusculus*, Sow., &c. A number of species of Belemnites also occur with some well-known Inferior-Oolite Lamellibranchiates and Brachiopods. It is clear, from the nature of its fauna, that this division must be assigned to the Zone of *Ammonites Murchisonæ*.

In the lowest part of the Lower-Oolite series of the Western Highlands I have detected a few fossils which seem to indicate the existence of a representative of the Midford Sand of England, and constitute a transition series into the Upper-Lias beds beneath. The horizon is not by any means well marked, and the very characteristic forms of Ammonites are, so far as I have been able to determine, wholly wanting in it.

Taken altogether, the Lower-Oolite strata of Skye, which are so well exhibited in their entirety in the fine cliff-sections above Prince Charles's Cave and the Holm Islet, and of which numerous partial exposures occur at the Beal, Scoribreck, and along the coast southward from Portree, may with great probability be regarded as representing both the Great and Inferior Oolite. But while it is quite certain that the divisions III. and IV. represent the lower part of the Inferior Oolite, some doubt still exists as to whether the divisions I. and II. should be regarded simply as the upper part of the Inferior Oolite, or as belonging in part to the Great Oolite also.

In the island of Raasay the Lower-Oolite beds appear in great force, but are exposed only in a series of vertical cliffs, which are almost everywhere perfectly inaccessible. From a comparison of the points at which the several members (which agree very closely in character with the strata already described in Skye) make their appearance, and a knowledge of the heights of certain points in the cliffs, we are able to appreciate how very grand is the development of the Lower-Oolite formation in these fine mural precipices of Raasay.

The estuarine conditions which prevail in the division II. of the Skye section are equally well marked in the equivalent beds in Raasay, and appear to extend down through a great part of the division III.; in this island, indeed, a thin seam of coal has been found in one place at the horizon in question. In this part of the series the strata appear to have even a greater thickness in Raasay than in Skye. The lowest division (IV.), too, appears to exhibit

more littoral conditions in Raasay than in Skye, the sandy micaceous shales being less predominant, while coarse sandstones and grits with calcareous concretions full of shells take their place.

The Lower-Oolite strata appear to occur as far to the northwards as the Shiant Isles; for in a visit which I paid to that isolated group of rocky islets in company with Dr. Taylor Smith I found masses of greatly altered shale enclosed between gigantic intrusive sheets of coarse dolerite, as described on a previous page (see p. 677). The intense metamorphism to which these shales had evidently been subjected had resulted in converting highly micaceous clays, in places becoming sandy and calcareous, into hard masses like Lydian stone, and in other cases causing them to pass into a remarkable rock with a pseudo-pisolitic structure developed in its midst. For a long time we searched in vain for any traces of fossils other than those recorded by Macculloch as occurring here, namely the hollow casts of Belemnites; but at last we were so fortunate as to detect flattened impressions of Ammonites, which I was able to identify as *Am. Murchisonæ*, Sow., and *Am. corrugatus*, Sow. The forms of the Belemnite-casts, too, are in some cases undoubtedly those of *Bel. giganteus*; so that I have little hesitation in affirming that in these most remote representatives of the Jurassic system in the Hebrides we have the lowest part of the Inferior-Oolite series. In the district of Strathaird beds of Inferior Oolite occur immediately beneath the great capping of basaltic lava; but here the amount of alteration which the beds have undergone, owing to their proximity to the axis of the great Skye volcano, is very great indeed, and only at a few points have I been able to detect obscure traces of the characteristic fossils of this horizon. Their relations to the underlying strata are, however, perfectly clear and unmistakable.

Still further south, in Ardnamurchan, the Inferior-Oolite strata again make their appearance, and, indeed, occupy a considerable area; but here, as in Strathaird and the Shiant Isles, they have undergone great alteration. They are frequently, indeed, found to be intersected by such a plexus of veins and dykes of igneous rock as to have lost all traces of stratification and every vestige of fossils; but by tracing these masses over a considerable distance, less altered patches may sometimes be found; and in such I have detected such characteristic fossils as *Ammonites Murchisonæ*, Sow., *Belemnites giganteus*, Schloth., *Rhynchonella spinosa*, Schloth., and several other well-known Inferior-Oolite forms.

Still further south the Inferior-Oolite strata are entirely cut off by the overlap of the Upper Cretaceous.

The thickness of strata of Inferior-Oolite age exposed in the Shiant Isles does not appear to be very great. There are evidently beds of somewhat different mineral characters exposed there, some being more calcareous, others more argillaceous in composition. Most of the beds were, however, originally clearly arenaceous in character; but all have undergone great metamorphism through being entangled in the great sheets of basaltic rock already described (see section, fig. 6, p. 677).

The various sections in Skye and Raasay have been so fully described, first by Sir Roderick Murchison and afterwards by Dr. Bryce and Prof. Tate, that it is not necessary to dwell further upon the details exhibited by them. Locally they often exhibit a considerable amount of metamorphism resulting from the action of the numerous sheets and dykes of dolerite by which they are traversed. The beds display in an eminent degree the character so frequently exhibited by strata of littoral origin, and undergo great variations in thickness and mineral character within very short distances.

The greatly altered Inferior-Oolite strata of Strathaird are incapable of throwing any new light on the general characters, order of succession, or fossil contents of this formation. Their true position in the geological series is, indeed, only rendered manifest by a study of their relations to the Upper- and Middle-Lias strata.

The Inferior-Oolite strata of Ardnamurchan are only one degree less metamorphosed than those of Skye; but by carefully examining some portions of the beds which have undergone less intense alteration, we may, as already mentioned, detect here and there a fossil enabling us to decide on the age of the beds.

Southward from Ardnamurchan no traces of the Inferior-Oolite strata have escaped being swept away by denudation till we reach the well-known development of the formation in Yorkshire, where they exhibit estuarine characters somewhat similar to those which distinguish their Scottish equivalents.

Similar estuarine conditions characterize the beds of the same age in the place of their most northerly development in Britain, namely Sutherland; and in fact purely marine representatives of the formation are found only in the extreme southern portions of our island. The formation is excessively variable in its thickness in different areas, and over large portions of the British islands it is probable that no beds of this age were deposited at all. But it is no less clear that the few fragments left of its strata afford but very imperfect indications of the extent of country over which it was originally deposited, extensive denudation both prior to the Cretaceous and subsequently to the Miocene having effected so much in the destruction of the deposits of this period.

f. *The Great Estuarine Series.*

Beneath marine strata of Oxfordian age in the Eastern Highlands there occur, as we have shown in the first part of this memoir, a series of estuarine strata which contain the famous coal-seam of Brora. In a somewhat analogous position in the Jurassic series of the western coast similar estuarine beds also make their appearance.

As we have already shown in the foregoing pages, the Lower Oolites of the Hebrides include certain beds which exhibit evidence of having been accumulated under littoral, occasionally passing into freshwater conditions. But strata of far more pronounced estuarine characters succeed the Lower Oolites of the Western Isles, and are intercalated between them and the representative of the Oxford

Clay. In Skye and Raasay these strata, which are probably not less than 400 or 500 feet in thickness, are very imperfectly exposed; but southwards, in the islands of Eigg and Muck, the series acquires far greater proportions, and its characters are capable of being much more accurately studied.

The estuarine strata of Jurassic age in the Western Highlands present, like those of the eastern coast of Scotland, two distinct types, the arenaceous and the argillo-calcareous; the former closely resembling in characters the English Hastings Sand, the latter presenting the most striking analogy in their general features with our Purbeck and Punfield series.

The Great Estuarine Series is best displayed along the north-west shore of the island of Eigg, from Sgor Scalleadh to Laig Bay. The divisions which can here be recognized, proceeding from above downwards, are as follows:—

feet.

- | | |
|--|-----|
| I. Strata of black shale, crowded in places with <i>Cypris</i> , and alternating with thin bands of argillaceous limestone. They are sometimes crowded with <i>Cyrena</i> and <i>Cyclas</i> ; but at others are full of <i>Paludina</i> , <i>Melania</i> , and other univalves. Beds, sometimes of great thickness, completely made up of the shells of <i>Ostrea hebridica</i> , Forbes, sometimes occur in the series, and these very closely resemble the Cinder-beds of the Purbeck series. Bands of fibrous carbonate of lime, like the "beef" and "bacon" bands of the same formation, also occur, and fish-remains, including both scales and teeth, are sometimes abundant | 150 |
| II. A great series of sandstone beds of white and grey tints, in places becoming very coarse-grained and passing into grits; occasionally, indeed, pebbles of white quartz become so numerous as to convert the rock into a conglomerate. These strata often exhibit much false-bedding, and their surfaces are sometimes found to be covered with ripple-marks, sun-cracks, and worm-tracks. In certain parts of the series the rocks contain a considerable quantity of carbonate of lime, and pass into calcareous grits. Thin coal-seams also occur in it. With the exception of plant-remains, which are at times found in a vertical position, the only fossils yet detected in this division are a few casts of <i>Cyclas</i> , and some other shells too imperfect for identification. A very striking feature often presented by the beds of this division is that the calcareo-siliceous rock contains great concretionary spheres, often many feet or yards in diameter; and striking mamillated and botryoidal forms also occur in it*. Owing to numerous and sudden changes in dip, the occurrence of frequent faults, and the interruption occasioned by intrusive sheets of dolerite, it is difficult to estimate the exact thickness of this series, but it would appear to certainly exceed | 500 |
| III. Laminated black shales and limestones like those of I., abounding in <i>Cypris</i> and fish-remains, and shells of <i>Cyrena</i> , <i>Cyclas</i> , <i>Paludina</i> , &c. Towards the base of the series beds of conglomerate and shelly limestone occur, which abound with freshwater shells, and also contain very numerous fish and reptilian remains, including remains of <i>Plesiosaurus</i> , Chelonians, &c. | 200 |

* Hugh Miller first noticed and described a peculiar property which the sands formed by the disintegration of these beds exhibit, namely, that of giving forth a musical note when pressed by the feet in walking over them.

In the northern part of the area we are describing, as in Skye and Raasay, only the divisions I. and II. occur, III. being wholly wanting, or, as is not improbable, represented by the more purely marine beds I. of the Inferior Oolite. The uppermost division of the Loch-Staffin beds, first described by Macculloch, was referred by Murchison, on account of the peculiar characters of its beds and the general facies of its fossils, to the Wealden; and its true position in the geological series, as underlying strata containing Oxfordian fossils, was first shown by Edward Forbes in 1851*.

These same strata can also be traced lying at the top of the whole series of Secondary strata both in Skye and Raasay. In the former island they are seen not only in the mural cliffs on the east side of the Trotternish peninsula, but extend some distance inland, and are exposed by the denudation of the overlying basaltic lavas around Lochs Leithan and Fada, as pointed out by the late Dr. Bryce. They again make their appearance, but at much lower levels, at other points around the Trotternish peninsula, as at Aird and Duntulm; but in all these cases the strata have undergone great changes owing to the intrusion into their midst, during Tertiary times, of great masses of igneous rock. Thus the sandy beds are found converted into chert and quartzite, the clays into a hard and brittle material, breaking with a conchoidal fracture, and resembling Lydian stone, and the limestones into saccharoid marble. Further west in Skye, in the peninsulas of Vaternish and Quirinish, strata belonging to this part of the series are exposed on the coast, where they are seen lying under the thick series of Miocene lavas at Stein in Loch Bay, and at Copnahow Head. These exposures are interesting, as showing how widely spread is the great foundation of Secondary rocks lying beneath the Miocene basalts which cover all the northern part of the island of Skye.

In the island of Raasay the Great Estuarine Series is presented to us with a series of relations remarkably parallel with those which prevail in Skye. On the eastern coast the strata in question are seen at a great elevation, occupying, indeed, the highest crest of the island immediately below the isolated cap of basaltic lavas of Dun Can, by which they have been saved from the destructive action of the denuding forces. The same strata, however, are found rapidly dipping westward, and pass under the sea-level along the east shores of the Sound of Raasay, which must hence be traversed by a great fault with a throw of something like 1000 feet.

Passing from the northern to the southern area, it is in the latter, as we have already seen, that the strata of the Great Estuarine Series acquire their most important development. This is well illustrated by the sections in the islands of Eigg and Muck. In the former we, in the north-western part of the island, have a tolerably continuous section of the whole of the strata, though the base is unfortunately concealed beneath the sea-level. The same beds appear on the eastern side of that island, but are there rendered obscure by

* Quart. Journ. Geol. Soc. vol. vii. p. 104.

the slipped masses of the overlying basalts. The upper divisions I. and II. resemble the equivalent strata of Skye and Raasay, but appear to have a somewhat greater thickness; while the lowest member, III., not represented in the northern localities, has in the southern area great thickness and importance.

The upper argillaceous series, which is fairly well exposed in Eigg, but much better in Muck, contains, as in Skye and Raasay, thick beds of dwarfed oysters (*O. hebridica*, Forbes), indicating a gradual transition into the marine Oxfordian beds above. Both in the northern and southern areas the argillaceous and arenaceous divisions of the Great Estuarine Series exhibit—as is so constantly the case with formations of this character—rapid and sudden changes in composition and thickness within very short distances.

The most southern exposure of the strata of this formation which is certainly known occurs in the island of Muck; and, as it has not been before described, I add a few notes on the section.

Fig. 9.—Section exposed in reefs seen at low water at Camus Mhor, in the Island of Muck.



- a. Grass-covered slopes.
- b. Shingle.
- c. Great bed composed of shells of *Ostrea hebridica*, Forbes.
- d. Laminated shales, with bands of hydraulic limestone.
- e. Oyster bands, with alternating limestones and shales.
- f. Shales and limestone containing *Cyclos*, fish-remains, &c.
- g. Calciferous sandstone (the lowest bed exposed).

The strata in question occur at the head of the little bay of Camus Mhor on the south side of the island, and consist of a number of beds forming reefs along the shore, with a dip inland of 5° (see fig. 9). These strata, of which probably the thickness exposed is not more than 20 or 30 feet, consist of thick masses of oysters intercalated with shale and limestone bands about 8 feet thick, lying upon beds of shale and limestone containing *Cyclos*, *Cyrena*, and some univalves. The lowest beds seen are somewhat more sandy in character. It is clear that all the beds of Camus Mhor in Muck belong to the division I. of the Great Estuarine Series, and it is not improbable that under the green slopes and shingle of the shore above traces of the overlying Oxford-Clay strata might be found.

It is quite possible that among the greatly altered rocks lying in close proximity to the gabbro-masses of the volcanic axis of Ardnarmurchan the Great Estuarine Series may be represented; but that such is actually the case I have not been able to obtain any clear and unmistakable evidence.

These estuarine strata, so conspicuously exposed in Sutherland

and the northern part of the Inner Hebrides, must have originally constituted a great formation comparable to the Wealden of the south-east of England in the thickness of its strata and the area which it covered. Like the Wealden, too, it was only developed over a somewhat limited area, being due to conditions that could not be expected to extend far. Hence the purely Estuarine infra-Oxfordian delta must be regarded, like its Neocomian analogue, as constituting an entirely local and exceptional phenomenon. And, though the fragments preserved to us by such remarkable accidents, both on the east and west coasts of Scotland, can only be regarded as forming a series of very minute vestiges of this great formation, we must bear in mind that in the southern part of the British area it was represented by strata of much less thickness, which were almost uniformly of *marine* origin.

It is, however, worthy of remark that it is where the Great Estuarine Series attains its greatest thickness and fullest development that it is suddenly cut off by the overlap of the Upper-Cretaceous rocks.

g. *The Oxford Clay.*

Immediately overlying the great series of estuarine strata just described, we find, both in Skye and Eigg, a mass of blue clays containing some subordinate bands of argillaceous limestone, which are undoubtedly of marine origin. The age of this set of clays is fortunately placed beyond doubt by the nature of the fossils which they yield; for these clearly represent the fauna of the middle portion of the Oxford Clay—the zone of *Ammonites cordatus*.

The fossils of these strata, which are tolerably numerous, but by no means well preserved, have been examined by Prof. Ed. Forbes, who gives a list of the forms obtained by himself from Loch Staffin; and by Mr. Tate, who enumerates those found by Dr. Bryce at Uig. It will be interesting to give, for comparison with these, the following list of species, collected either by myself or Mr. Hugh Miller at the Bay of Laig, in the island of Eigg:—

Fossils of the Oxford-Clay Beds from the Bay of Laig, Island of Eigg.

Belemnites sulcatus, <i>Mill.</i>	Ostrea Roëmeri, <i>Quenst.</i>
— gracilis, <i>Phill.</i>	Avicula expansa, <i>Phill.</i>
Ammonites Williamsoni, <i>Phill.</i> (=A. arduennensis, <i>D' Orb.</i>).	— braamburiensis, <i>Sow.</i>
— Toucasianus, <i>D' Orb.</i>	Arca, ? sp.
— cordatus, <i>Sow.</i> (Several varieties of this species are very abundant.)	Nucua, sp.
— excavatus, <i>Sow.</i>	Lucina, ? sp.
— Mariae, <i>D' Orb.</i>	Astarte (near A. minima, <i>Phill.</i>).
— Lamberti, <i>Sow.</i>	Serpula.
— Sutherlandia, <i>Sow.</i> Young forms.	Dorsal spine of fish.
	Wood and vegetable remains abundant.

The Oxford-Clay strata of the Western Isles are nowhere well

developed, nor do they at any point in the area exhibit clear or continuous sections. They appear to consist of dark blue shales, perfectly similar in character to the Oxford Clay of England, and containing septarian nodules, masses of pyrites, and occasionally much wood in the form of jet. At some localities they include irregular bands of argillaceous limestone.

Although so imperfectly exposed, it is clear, from the nature and position of the fragments of the formation which are seen, that beds of this age must underlie great tracts of the Miocene basalts of the Hebrides. The strata, too, are not improbably of very considerable thickness, although the slipping of the basaltic masses over them wherever they make their appearance prevents us from making any approach to an estimate of that thickness.

It is, indeed, to this slipping of the great masses of columnar and massive lava rocks upon the insecure foundation of the Oxford Clay that the striking scenery of the eastern side of the Trotternish peninsula, so well exemplified by the Quiraing and the Storr rocks, owes its origin. Here the Oxford Clay appears at great elevations, its fossils being collected occasionally during drainage-operations; while westward it dips away like the underlying estuarine beds, and disappears beneath the sea-level. Traces of it, however, are found at Duntulm, Mugstock, Uig, and some other points.

In Eigg, at Laig Bay, the same beds, with precisely similar characters and fossils, occur, but are only exposed at a few points along the shore at low water; they can only be satisfactorily examined during spring-tides. Possibly, although concealed by shingle and vegetation, a trace of the same set of strata occurs in the neighbouring island of Muck. To the southward, however, no traces of the formation have been detected.

Although the Oxford-Clay strata of the Western Highlands are so strikingly similar in character to those of England, the beds on which they repose are, as we have seen, of entirely different character. With respect to the question of the strata which may have been deposited above these Oxfordian rocks of the Hebrides, I will only refer to what I have already said as to the unreliability of the negative evidence in this case, and to the possibility, if not the probability, of rocks of Upper-Oolite and Neocomian age having originally existed in the Western as well as in the Eastern Highlands.

The Oxford Clay of both Scotland and England must have been deposited in a sea of considerable depth; and it is probable that its beds originally extended over a great part, at least, of what is now the area of the British Islands. Indeed, so strikingly similar is the formation in its mineral characters and the succession of its forms of life over the greater portion of the Anglo-Germanic area, that there can be no doubt as to the Oxfordian sea of that life-province being of very wide extent, as well as of considerable depth, and not broken up into a number of isolated portions. We find, however, in Yorkshire and elsewhere, indications of the prevalence of more littoral conditions, proving probably that some islands rose above the surface of this great Oxfordian sea. The position and relations of these, so

far as they can be now ascertained, I hope to discuss on a future occasion.

D. THE CRETACEOUS SYSTEM.

The Cretaceous strata of the Western Highlands, although of no great thickness, are of surpassing interest. The fact of their presence in the area in question is one which, as we have already pointed out, is full of significance to the geologist who seeks to realize the vastness of the changes in physical geography of the Highland districts which have taken place during successive geological periods. But when the peculiar and anomalous character presented by these beds in the Scottish area comes to be fully appreciated, their important bearing on many great questions of theoretical geology must be apparent to every one; and the suggestiveness of the facts is enhanced when we compare the Scottish Cretaceous beds with their equivalents in other parts of Northern Europe and America.

As we have already pointed out, no vestiges of Neocomian strata have as yet been found in any part of the Western Highlands; but we have sufficiently insisted on the danger of accepting the negative evidence as being conclusive against such strata having ever been deposited within the district. From a careful consideration of all the facts of the case, I believe there are strong grounds for the presumption that very large areas in the Highlands were once covered by strata of Upper-Oolite and Neocomian age, the former being certainly represented by deposits of great thickness and importance.

The Upper Cretaceous strata, though represented at the present day by such minute and inconspicuous patches, must once have had a wide range, and in places probably attained a considerable thickness. It is clear, from the abundance of chalk-flints in certain Miocene inter-volcanic deposits, such as those of Ardtun and the Innimore of Carsaig, that very extensive masses of Chalk must have been destroyed by denudation in order to supply the quantities of flints accumulated in those deposits. It is probable, indeed, that very considerable masses of strata of Cretaceous age still exist buried under the great lava plateaux of Mull and Morvern.

The Upper Cretaceous strata of the Western Highlands rest everywhere unconformably upon the older rocks. Thus at Carsaig they are seen reposing directly upon the Middle Lias; at Loch Aline they overlap successively the Lower Lias, the Infra-lias, and the Poikilitic; while at Gribun they appear to lie in part on Poikilitic strata, and in part on the old gneissic rocks, which are presumed to be of Lower Silurian age.

The succession of deposits belonging to the Upper Cretaceous in the district of the Western Highlands is very peculiar; for we there find the strata of this age assuming those littoral and estuarine conditions which are so strikingly exhibited by the underlying Jurassic beds. As might be expected under such circumstances, the Cretaceous beds exhibit very rapid and remarkable changes in thickness

and character even within exceedingly short distances. The strata represented may be exhibited in a tabular form as follows, proceeding from above downwards :—

	feet.
I. Sandstones and white marls, with numerous plant-remains and occasional thin seams of coal. The Miocene basalts and volcanic tuffs are seen to repose upon eroded surfaces of this set of beds. This series is nowhere exposed in a section of more than 20 feet; but what its full thickness may have originally been, we have no means of judging	20
II. Beds of white indurated Chalk with bands of flints. The Chalk itself is usually converted into an almost purely siliceous rock, the various minute organisms in it, however, being still recognizable. The fossils in these beds are all marine. Though no section more than 10 feet in thickness of these beds can be anywhere seen, yet it is evident that in places they must have attained a very considerable development. Only here and there, however, can they be traced, where some fortunate accident has exposed the base of the great superincumbent masses of basaltic lava.....	10+
III. Beds of white sandstone, without fossils, occasionally containing many white quartz pebbles, and passing into conglomerate. These beds have yielded no vestiges of marine life, but in places contain much carbonaceous matter, and at one point a seam of coal has been detected in their midst. Their thickness is very variable, averaging about	100
IV. Glauconite sandstone (greensand). Often highly calcareous in its upper part and passing into limestone, but still containing the characteristic grains of glauconite. At other points it passes into an areno-argillaceous rock of a dark green colour, very similar in appearance to portions of the Hibernian Greensand. The fossils in these beds are very numerous and entirely of marine forms; although individuals are so abundant, however, the number of species is by no means very great. The thickness of this marine series is very variable, the maximum may be taken at	60

We thus see that the Upper-Cretaceous series in the Western Highlands consist of four members, two marine and two estuarine. The exact age of the marine strata can be fixed precisely by the fossils which they contain, that of the estuarine beds can only be inferred from their relations to the marine series.

The lowest series of beds (IV.) unquestionably represents the Cenomanian or Upper Greensand, and in its mineral characters greatly resembles the equivalent strata in England and Ireland. The fossils which it contains place this identification beyond doubt; they include the following species :—

<i>Nautilus Deslongchampsianus</i> , <i>D'Orb.</i>	<i>Pecten orbicularis</i> , <i>Mant.</i> (abundant).
<i>Exogyra conica</i> , <i>Sow.</i> (very abundant).	— <i>quinquecostatus</i> , <i>D'Orb.</i>
— <i>halioतोidea</i> , <i>Sow.</i>	<i>Serpula</i> , <i>sp.</i>
—, <i>sp.</i>	—, <i>sp.</i>
<i>Pecten asper</i> , <i>Lamk.</i>	<i>Spongia paradoxa</i> .

Unfortunately no Ammonites have been detected in the Scottish deposits; and it seems probable that the Upper Greensand of this northern area was deposited under more littoral conditions than the strata of the same age in England.

The series II. contains *Belemnitella mucronata*, Schloth., with a

coral and many fragments of *Inoceramus*. Its age is clearly the same as that of the greater part of the White Limestone of Ireland and of the highest beds of Chalk in England.

The Estuarine series (III.) may be fairly regarded as representing the whole or a portion of the Chalk series intervening between the Upper Greensand on the one hand, and the Chalk with *Belemnitella mucronata* on the other.

The age of the Upper Estuarine series (I.) is more doubtful. It appears to be so closely connected with the series below, that I am strongly inclined to regard it as of Cretaceous age, and either as representing one of the higher members of the Chalk (the Faxoe or Meudon beds) not elsewhere developed in this country, or as deposited in the interval between the Cretaceous and Eocene periods. But it is by no means impossible that future research may demonstrate these beds to belong to the Tertiary and to be of Eocene or even later date.

Thus we have arrived at the conclusion that while the series IV. represents the Upper Greensand; III., II., and I. must in all probability be regarded as constituting an abnormal development of the English Chalk. It will be convenient to discuss the characters of these two sets of deposits separately.

In the northern portion of the Western Highlands no trace of the Cretaceous strata has yet been detected; and, indeed, the whole of the strata show a tendency to thin out in that direction. We must not, however, overlook the possibility that beds of this age may once have existed there and have been wholly removed by denudation; and this caution will more especially appear to be necessary when we remember the deposits of chalk-flint in Aberdeenshire, which seem to prove the extension of the Cretaceous ocean in that direction.

a. *The Upper Greensand and associated Beds.*

Perhaps the best exposures of the Upper-Greensand strata are those which occur about Carsaig, on the south side of the island of Mull; and it is here that I first detected the presence of beds of this age in 1872.

Above Carsaig House, and in the midst of woods that clothe the precipices which shelter this beautiful spot, there is an old quarry, from which, when the house was originally built, masses of stone were thrown down for burning into lime. This stone is found to be crowded with fossils of the Upper Greensand, *Exogyra conica* occurring in the greatest profusion, and *Pecten orbicularis* being by no means rare.

The section here is by no means clear or well exposed. At two separate points I have detected masses of the altered chalk- and flint-beds squeezed out from beneath the mass of superincumbent basalt; but further than the fact that these beds overlie the Greensand, it is impossible to obtain any light on the true relations of the members of the Cretaceous series here. The section (fig. 10) shows the general relations of the beds exposed in the cliffs at Carsaig.

Fig. 10.—Generalized Section of the Strata exposed at Carsaig, on the South shore of the Isle of Mull.

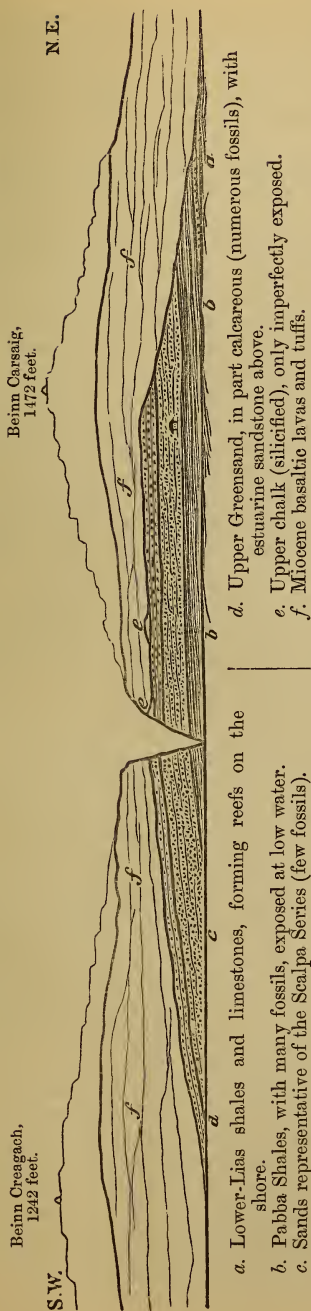
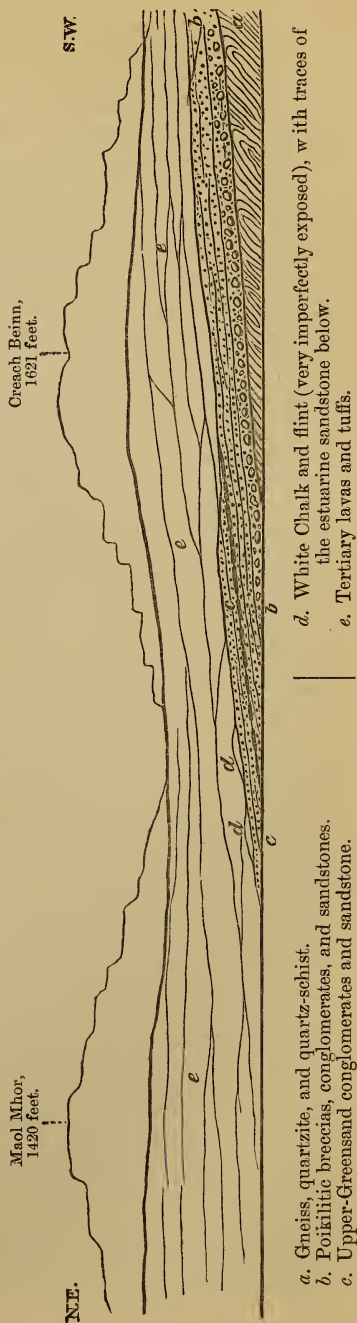


Fig. 11.—Generalized Section at Gribun, Isle of Mull.



The Upper Greensand itself appears to consist of two portions, the higher calcareous, the lower arenaceous. The calcareous beds derive their character from being almost wholly made up of shells of *Exogyra conica*, and are in fact great oyster-banks. Both the calcareous and the arenaceous beds contain the characteristic grains of glauconite.

The Upper Greensand behind Carsaig House is found to rest directly upon the sandy strata of the Middle Lias (Scalpa Series). When traced westwards, however, the Greensand is found occupying gradually lower levels, owing to a dip in that direction, till at last it reaches the sea-level at a point beyond the celebrated Nun's Cave. Throughout the whole of its exposure on this coast the strata are crowded with *Exogyra* and other shells; but the beds of highly calcareous character appear to be somewhat local, and do not seem to occur at the westernmost exposures of the formation.

The next place at which the Upper-Greensand strata are exposed is about Loch Aline. Here the beds in question are found overlapping the Lower-Lias strata, and can be well studied on the shore along the western shores of the Loch, at a little distance above the inn and village. None of the strata are here so highly calcareous as above Carsaig House; but beds of dark green clayey sand occur at several points in the series. The fossils are abundant and of the same species as at Carsaig.

The Upper-Greensand strata presenting everywhere the same characters, but apparently diminishing in thickness as we go northwards, can be detected around the head of Loch Aline, about Loch Arienas, and, finally, in the remarkable outliers of Morvern, where the most northerly exposures of the beds of this age occur.

At Gribun on the shores of Loch-na-Kael and in the opposite islet of Inch Kenneth, the Upper Greensand makes its appearance and presents somewhat different features from those which characterize it at the localities already described. The strata there are found resting directly upon the Poikilitic beds already noticed, and, indeed, are largely formed of the materials derived from those beds. Under these circumstances it is not surprising that the line of division between the Cretaceous above and the Poikilitic below is often very obscure. While the upper part of the Greensand here consists of the ordinary glauconitic sands, in which I have detected the common *Exogyra conica*, species of *Serpula*, and *Spongia paradoxo*, the lower part consists of a conglomerate of quartzite pebbles derived directly or indirectly from the old gneissic rocks of the district, upon which the Poikilitic strata here rest. There are grounds, indeed, for believing that the Upper-Greensand strata here completely overlap the Poikilitic beds, and rest directly upon the old gneiss rocks themselves. At two or three points at Gribun the peculiar beds of the Scottish Chalk—here converted into a siliceous material—are seen crushed out from beneath the overwhelming masses of basaltic lava that cover all the Secondary strata to such a great depth at this place. The accompanying section (fig. 11, p. 731) illustrates the general relations of the beds seen at Gribun.

As affording indications of the existence of an old beach of the Cretaceous sea, these beds of Gribun and Inch Kenneth are of very great interest to the geologist; and, but for the occurrence of the characteristic fossils in their upper part, it would be impossible to discriminate the beds of pebbles which compose them from those of the underlying Poikilitic series, the reconstructed materials of which form so large a proportion of their mass.

b. *The Strata representing the Chalk.*

In speaking of the Upper-Greensand beds we have already had occasion to notice the small masses of altered Chalk at Carsaig and Gribun. Although converted into a siliceous rock, the fact that this chalk was originally calcareous (that is, made up of shells of Foraminifera, with fragments of *Inoceramus* and other organisms common in the English Chalk) is made perfectly clear by the study of thin sections of the rock by the aid of the microscope. In this examination of the Scottish Chalk, I have received much aid and many valuable suggestions from my friends Professors W. K. Parker and T. Rupert Jones. To the latter I am indebted for the note on the organisms occurring in a series of sections which I had prepared of these rocks, which is printed at the end of this paper (p. 739).

Although there are several other points in the island of Mull at which strata probably belonging to different parts of the Upper Cretaceous occur, yet at all these places the relations of the beds are so obscure, or their characters have been so completely modified by the influence of the great volcanic masses in their neighbourhood, that it would not be safe to pronounce with confidence on the age of any of them.

In Morvern, however, the characters and relations of the strata representing the Chalk can be more perfectly made out. On both sides of Loch Aline and along the south shore of Loch Arienas the Greensand strata are covered by thick masses of coarse white sandstone, locally assuming variegated tints. These contain no fossils, but from their stratigraphical relations can be safely correlated with the Middle and Lower Chalk of England. This mass of sandstone strata varies greatly in thickness and characters, but seldom, if ever, exceeds 100 feet. It contains no fossils, but exhibits evidence of having been accumulated under estuarine conditions.

The most interesting of all the sections of the representatives of the Chalk strata, however, are those which occur beneath the singular outlying masses of Beinn-y-Hun and Beinn-y-Hattan, in the same district of Morvern, where they are preserved by the singular accident already described. (See the section, Plate XXXI. fig. 2.) There are, however, only a few points along the lines of outcrop of these beds where the succession of strata can be satisfactorily made out.

In Beinn-y-Hun the masses of coarse estuarine Sandstone representing the Lower and Middle members of the Chalk are fairly well seen, and are probably nearly 100 feet in thickness. In the midst of these sandstones Macculloch found a thin seam of lignite or coal;

and I have been told by the shepherds who frequent the mountain, that such a seam of coal, two or three inches in thickness, is sometimes exposed after great falls have taken place from the sandstone cliffs. The surface of these sandstone strata in Beinn-y-Hattan has evidently been subjected to subaerial denudation before the Miocene basaltic lavas were poured out above them. In some cases the base of the lava-streams is seen to contain numerous angular fragments of the sandstone, which have been converted into a substance resembling quartzite; in other instances the surfaces of sandstone over which the lava has flowed have been broken up into hexagonal columns by the contraction of the mass in consequence of its being heated and desiccated. The Cretaceous strata of Beinn-y-Hun, like those seen in the cliffs on the opposite side of Lake Arienas, probably rest unconformably on Poikilitic marls, sandstones, and conglomerates; but owing to the quantities of talus at the base of the cliffs of Secondary strata, these rocks are very imperfectly exposed. The outlier of Secondary strata in Beinn-y-Hun, which is capped by a mass of Miocene basalts about 250 feet thick, is traversed by a considerable fault with a throw of from 300 to 400 feet, which appears to be parallel with the far greater fault which traverses the Innimore of Ardtornish, and limits the outlier of Beinn-y-Hattan on the east.

In Beinn-y-Hattan, which rises to the height of 2308 feet above the sea-level, the cap of Miocene basalts is much thicker than in Beinn-y-Hun, attaining to no less than 600 or 800 feet. The series of Secondary strata exposed below the basalts, too, is of far greater interest in the former mountain than in the latter. The nature and succession of these Secondary strata will be best illustrated by one or two detailed sections obtained at points where streams have cut through the masses of talus that usually obscure the cliffs formed by the softer Secondary rocks lying at the base of the great basaltic precipices that constitute the mountain-peak. The Secondary strata lie directly upon the old gneiss rocks, and the overlying basalts are evidently relics of great and wide-spreading lava-currents; they are frequently columnar, and alternate with tuffs, burnt soils, &c. The Secondary strata, both in Beinn-y-Hun and Beinn-y-Hattan, are traversed by numerous basaltic dykes; one of these on the latter mountain, consisting of horizontal columns, forms a very striking and beautiful object.

Section obtained at the east end of Beinn-y-Hattan, Morvern.

		ft.	in.
1. Miocene basaltic lavas alternating with tuffs &c.			
Beds of reddish-brown volcanic ash.....		15 to 20	
Upper estuarine series (a few feet only in thickness).	(a) Thin seam of lignite	0	2
	(b) Laminated greyish clay with much carbonaceous matter and many obscure plant-remains	8 in. to 1	
	(c) Grey chalky bed, not constant, consisting of whitish marl with plant-remains, containing angular fragments of the underlying Chalk. This bed appears to afford evidence of the upheaval of the marine beds before its deposition	0 to 1	6

Upper Chalk.	(d)	White Chalk converted into a siliceous rock, with flints. This rock abounds with fragments of <i>Inoceramus</i> and <i>Globigerinae</i> . It has yielded also <i>Belemnitella mucronata</i> , Schloth. sp., and some other fossils in a very imperfect condition	ft.	
	(e)	Bed of argillaceous limestone, with many irregularly shaped nodules and glauconite grains	1 to	2
	(f)	Argillaceous greensand	4 to	5
(These beds represent the zone of <i>Belemnitella mucronata</i> .)				
Estuarine Beds.	(g)	Coarse white sand, with a few green grains in the upper part	10 to	12
	(This bed probably represents, in a greatly diminished condition, the lower of the two Cretaceous estuarine series.)			
Up per Greensand	(h)	Bed of Greensand, becoming calcareous in places and crowded with <i>Exogyra conica</i> , Sow., <i>Pecten orbicularis</i> , Sow., and <i>Vermicularia</i> (several species), with other common Cenomanian fossils	1	
	(i)	Greenish argillaceous sand	5?	
Lias.	(k)	Blue-lias shales and limestones crowded with the usual fossils— <i>Gryphæa arcuata</i> , Lam., <i>Unicardium cardioides</i> , Phil. sp., <i>Lima pectinoides</i> , Sow. sp., <i>Cardinia Listeri</i> , Sow. sp., <i>Pentacrinus</i> , sp., &c.	6	
	(Lower Lias.)			
Poikilitic.	(l)	Variegated sands, marls, and concretionary limestone, with beds of grit and conglomerate, lie at the base of the series and rest on the old gneiss rocks, but are very imperfectly seen at this point.		

The total thickness of strata lying between the basalt above and the gneiss below in Beinn-y-Hattan is probably from 100 to 120 feet in thickness.

As showing the variation in thickness and character of the beds at short distances, I may cite another section taken at a point not far removed from the last:—

1. Basalt lava, scoriaceous at its base.	ft.	in.
Bed of indurated reddish-brown volcanic ash	10 to	12
(a) Thin coal-seam		1 to 2
(b) Underclay	6 in. to	1
(c) White, highly siliceous chalk with flints	3	
(d) Sandy bed with glauconite grains and irregular concretionary nodules	3?	
(e) White coarse sand	15?	

Beneath the last bed the representatives of the Upper Greensand, the Lower Lias, and the Poikilitic can be certainly made out; but the sections are too obscure to enable us to estimate the thickness of the several beds.

Another interesting section of the Secondary strata is found at the south-east angle of Beinn-y-Hattan, where the succession of beds is as follows:—

Miocene Basalts.		ft.	in.
Upper estuarine series, 4 ft. 6 in.	(a) Thin seam of grey marl	0	1
	(b) Black carbonaceous and micaceous sand	0	3
	(c) Brown micaceous sand, passing down into white and grey sand of a coarse character. Many carbonaceous markings	3	0
	(d) Whitish grey marl with plant-remains	1	0
	(e) Laminated grey marl with seam of impure lignite	0	2
Chalk.	(f) Band of weathered chalk-flints	1	0
	(g) White highly-siliceous chalk (only imperfectly exposed here)	3	0?
Lower estuarine.	(h) Sands (not well seen)	10	0?
	(i) Coarse white sands, becoming greenish and glauconitic at the base.....	20 to 30	0
Upper Greensand.	(k) Calcareous greensand with shells	0	6
	(l) Greensand with fossils	1	0
	(m) Dark green glauconitic sands crowded with shells	3	0
	(n) Calcareous greensand with several bands of shells	6	0
	(o) Glauconitic sands crowded with fossils	1	6
	(p) Greenish grey sand with many quartz-pebbles and much glauconite in its lower part	6	0
	(q) Grey sand, greenish and glauconitic in places	10	0
	(r) Hard calcareous band with a few fossils	6 in. to 1	0
	(s) Grey glauconitic sand	5	0
	(t) Beds of indurated greensand with only a few fossils ...	10	0
(Very strong springs arise at the base of this last bed.)			

An abstract of the section at this point gives the following as the thicknesses of the several formations :—

- | | |
|----------------------------------|-------------|
| (1) Upper estuarine strata | 4 ft. 6 in. |
| (2) Upper Chalk (marine)..... | 3 to 4 ft. |
| (3) Lower estuarine strata | 35 ft. ? |
| (4) Upper Greensand..... | 44 ft. |

The Lower Lias and Poikilitic, which lie below the Cretaceous strata here, have probably a united thickness of about 50 feet.

The only locality, besides the outliers already described, in which I have found any traces of the Upper series of estuarine strata forming the top of the Cretaceous series is in a little glen to the south-east of Ardtornish Towers, which, from the fact that some two tons of impure lignite were once obtained from it, is known as "the Coal Glen." The section here is unfortunately very obscure indeed; and I could only determine the fact that the lignite-beds in question lie between the Miocene basalts and tuffs above, and red sands, clays, and concretionary limestones of the Poikilitic series below. It is possible, however, that if a more complete section were obtainable, the succession of strata would be found similar to that seen in Beinn-y-Hattan. The age of this upper series of estuarine beds must still be regarded as doubtful. From their apparent close connexion with the strata below, I am inclined to consider them as Cretaceous, and as representing beds younger than any part of the Chalk of the British islands; but it is quite possible that they may

Formations.	Nature of the Bed.	Approximate Thickness.	Characteristic Fossils.	Localities.	Equivalents.
CHALK.	White marly and sandy beds, with thin seams of lignite.	feet. 20+	Plant-remains (species indeterminate).	Beinn-y-Hattan. The "Coal Glen" ? } Morvern.	Maestricht and Meudon beds ? or Eocene?
	White chalk (usually silicified), with flints.	10+	<i>Belennitella mucronata</i> , Schloth.; <i>Isocrani</i> ; Corals; Foraminifera; Sponges.	Carsaig; Gribun; Beinn-y-Hattan.	Zone of <i>Belennitella mucronata</i> . Upper Chalk.
	Thick white sandstones (occasionally variegated) with some carbonaceous matter.	100	Obscure plant-markings.	Carsaig; Gribun; shores of Loch Alino; Beinn-y-Hun; and Beinn-y-Hattan.	Middle and Lower Chalk.
UPPER GREEN-SD. ORFORDIAN.	Glaucous sands, with some beds of more argillaceous character, the whole occasionally assuming a calcareous character and passing into shelly limestones.	60	<i>Eragryra conica</i> , Sow.; <i>E. haliofoidea</i> , Lamk.; <i>Nautilus Deslongchampsiana</i> , D'Orb.; <i>Pecten asper</i> , Lamk.; <i>P. orbicularis</i> , Sow.; <i>Janira quinquicostatus</i> , Sow. sp.; <i>Serpula</i> , sp.; <i>Spongia paradoxa</i> .	Carsaig and the Innimore of Carsaig; Orribun; Inch Kenneth; Loch Aline; Beinn-y-Hun; Beinn-y-Hattan.	Upper Greensand. Cenomanian.
GREAT UNCONFORMABLE BREAK.					
MIDDLE ORFORDIAN.	Dark blue clays, with septarian nodules and some irregular bands of argillaceous limestone.	? Very considerable.	<i>Belennites salcatus</i> , Mill.; <i>B. gracilis</i> , Phill.; <i>Ammonites cordatus</i> , Sow. (varieties); <i>A. Williamsi</i> , Phill.; <i>A. Toucaianus</i> , D'Orb.; <i>Ostrea Römeri</i> , Quenst.; <i>Avicula expansa</i> , Phill.; <i>A. Braamburienensis</i> , Sow.; vegetable remains.	Laig Bay; I. of Eigg; Loch Staffin; Mugstock; Uig Bay; Duntuba.	Middle Orfordian.
GREAT ESTUARINE SERIES.	Alternating shales and shelly limestones, with bands of oysters and of fibrous carbonate of lime.	150	<i>Ostrea hebridea</i> , Forbes; <i>Corbula MacNeilli</i> , Mor.; <i>C. hebridea</i> , Forbes; <i>Mytilus caucatus</i> , Sow.; <i>Trigonia tripartita</i> , Forbes; <i>Aconia astuarina</i> , Tate; <i>Pholadomya aculeata</i> , Sow.; <i>Peria Marchisonae</i> , Forbes; <i>Scrita stajkensis</i> , Forbes; <i>N. arata</i> , Tate; <i>Hydrobia precursor</i> , Sundb.; <i>H. caldonica</i> , Tate; <i>Cyrena Jamesoni</i> , Forbes; <i>C. Cunninghami</i> , Forbes; <i>C. Drycei</i> , Tate; <i>C. arata</i> , Forbes; <i>C. Maccullochi</i> , Forbes; <i>Estheria Murchisonae</i> , T. R. Jones; Cyprids, Fish-remains, &c.	Camus Mhor; I. of Muck; Laig Bay, I. of Eigg.	Lower Orfordian and Great Oolite.
	Thick masses of white and grey sandstone, sometimes conglomeratic and occasionally calcareous; exhibiting globular concretions and mammillated surfaces with ripple- and fucoid-markings, &c.	500+	Wood- and plant-remains. Casts of <i>Cyclas</i> or <i>Cyrena</i> .	North-east and north-west shores of I. of Eigg; Serepidale, I. of Raasay; cliffs of Trotternish in Skye.	
	Laminated black shales and limestones, with bands of oysters and fibrous carbonate of lime.	200+	<i>Ostrea hebridea</i> , Forbes; <i>Cyclas</i> , sp.; <i>Cyrena</i> , sp.; <i>Estheria Murchisonae</i> , T. R. Jones; Reptilian- and Fish-remains.	North end of I. of Eigg; Serepidale in I. of Raasay; cliffs of Trotternish in Skye; Lochs Leatban and Fada in Skye; Copnash Head, Skye; Loch Bay, Skye.	
LOWER OOLITES.	Limestones almost wholly made up of conminuted shells.	45	<i>Ostrea Sowerbyi</i> , M. & L.; <i>Avicula contorta</i> , Sow.; <i>Lima gibbosa</i> , Sow.; <i>Terebratula laevis</i> , Sow.; <i>Rhynchonella concinna</i> , Sow.?		Inferior Oolite. Zone of <i>A. Parkinsoni</i> ?
	Beds of white sandstone, with some thin shaly bands, and often containing much carbonaceous matter.	60	Remains of <i>Ferus</i> and <i>Cyenda</i> .		?
	Alternating beds of sandstone and shale, the former containing great globular concretions and passing into shelly limestones.	160	<i>Belennites giganteus</i> , Schloth.; <i>B. alensis</i> , Voltz; <i>Ammonites Humphriesianus</i> , Sow.; <i>A. Blagdeni</i> , Sow.; <i>A. coronatus</i> , Schloth.; <i>A. comensis</i> , Von Kuch; <i>Pecten lens</i> , Sow.; <i>Pecten personatus</i> , Goldf.; <i>Terebratula pervalis</i> ; <i>Rhynchonella concinna</i> .		Zone of <i>A. Humphriesianus</i> .
UPPER LIAS.	Sandy micaceous shales alternating with calciferous sandstones, exhibiting globular concretions and mammillated surfaces.	120	<i>Belennites giganteus</i> , B. sp.; <i>Ammonites Murchisonae</i> , Sow.; <i>A. corrugatus</i> , Sow.; <i>A. levisculus</i> , Sow.; <i>Lachia Wrightii</i> , Op.; <i>Avicula inequivalvis</i> , Sow.; <i>Pleuronoma jurassica</i> ; <i>Ostrea</i> , sp.; <i>Cucullaea cancellata</i> ; <i>Avicula Hammeri</i> , Dehr.	Serepidale, I. of Raasay; cliffs of Trotternish, Skye; Tor Inivaig, Skye; Shiant Isles; Strathaird, Skye; Ardnurchan.	Zone of <i>Ammonites Murchisonae</i> .
	Finely laminated blue clays, with argillaceous and pyritous nodules and some jet.	100	<i>Belennites Voltzi</i> ; <i>B. inornatus</i> ; <i>Ammonites communis</i> , Sow.; <i>Am. radians</i> , Rein.; <i>Am. serpentinus</i> , Rein.; <i>Am. elegans</i> ; <i>Am. bifrons</i> , Brug.; <i>A. heterophyllus</i> , Sow.; <i>Posidonomya Bronni</i> ; <i>Isocranius dubius</i> , Sow.	Serepidale, I. of Raasay; Fearn, Raasay; cliffs of Trotternish, Skye; Tor Inivaig, Skye; Strathaird, Skye.	Upper Lias Clay.
MIDDLE LIAS.	Calcareous sandstones highly micaceous, sometimes ferruginous, and at times becoming more or less argillaceous in character. In the southern area represented by soft greenish sandstone, with little calcareous matter.	200	<i>Belennites elongatus</i> , Mill.; <i>Ammonites spinatus</i> , Brug.; <i>A. margaritatus</i> , De Montf. (varieties); <i>Cryptæna expansa</i> , Sow. sp.; <i>Pholadomya ambigua</i> , Sow.; <i>Avicula inequivalvis</i> , Sow.; <i>Lima Hermannii</i> , Voltz; <i>Pecten equidens</i> , Sow.; <i>P. sublevis</i> , Phill.; <i>P. lasius</i> , Nyst; <i>Plicatula spinosa</i> , Sow.; <i>P. levigata</i> , D'Orb.; <i>Gryphaea gigantea</i> , Sow.; <i>Rhynchonella tetraktra</i> , Sow.; <i>R. bideus</i> , Phill.; <i>R. acuta</i> , Sow.; <i>Terebratula resipicata</i> , Sow.; <i>T. punctata</i> , Sow.; <i>Prætorinus</i> , &c.	South end of I. of Raasay; I. of Scalpa; Peninsula of Trotternish, Skye; Tor Inivaig, Skye; Strathaird, Skye; Ardnurchan; Duart, I. of Mull; Carsaig, I. of Mull.	Zones of <i>Ammonites spinatus</i> and <i>A. margaritatus</i> .
	Dark-coloured micaceous shales, with many limestone nodules. In places the beds become more or less sandy in character.	200	<i>Belennites elongatus</i> , Mill.; <i>B. parvulus</i> ; <i>Ammonites Jamesoni</i> , Sow.; <i>A. brevispina</i> , Sow.; <i>A. polymorphus</i> ; <i>A. Davei</i> , Sow.; <i>Cheuniztia Blainvillei</i> , Benz; <i>Tectaria imbricata</i> , Sow. sp.; <i>Pholadomya decorata</i> ; <i>P. ambigua</i> , Sow.; <i>Pleuronoma ovata</i> , Rein.; <i>P. Seelica</i> , Wr.; <i>Unicardium lauræ</i> , D'Orb.; <i>Pinna folium</i> , Y. & B.; <i>Mytilus scalprum</i> , Sow.; <i>Gryphaea cymbium</i> , Lam.; <i>Plicatula spinosa</i> , Sow.; <i>P. levigata</i> , D'Orb., &c.	I. of Pubba; cliffs at Tor Inivaig; Leac, Raasay; Ardnurchan; Duart, I. of Mull; Carsaig, I. of Mull.	Zone of <i>A. Jamesoni</i> .
	Similar dark-blue micaceous shales, crowded with fossils. (Sandstone beds in places.)	100?	<i>Ammonites armatus</i> , Sow.; <i>A. oxyotus</i> , Quenst.; <i>A. ibex</i> , Quenst.; <i>A. l'aldani</i> , D'Orb.; <i>Leda coviplanata</i> , Phill. sp.; <i>Gryphaea obliqua</i> , Goldf.; <i>Plicatula spinosa</i> , Sow.; <i>P. levigata</i> , D'Orb.; <i>Unicardium cardioides</i> , Phill. sp.; <i>Lima punctata</i> , Sow.	Hallaig, I. of Raasay; Tobermory; I. of Mull.	Zones of <i>Ammonites armatus</i> , <i>A. ibex</i> , and <i>A. oxyotus</i> .
LOWER LIAS.	Dark-coloured sandy and micaceous shales, with some bands of shelly limestone.	150	<i>Ammonites semicostatus</i> , Y. & B.; <i>A. Sauvannae</i> , D'Orb.; <i>A. Brooki</i> , Quenst. (non Sow.); <i>Gryphaea arcuata</i> , Lamk. var.; <i>Lima gigantea</i> , var., Sow.	I. of Raasay; Obe Breakish, I. of Skye; Mingary; Ardnurchan; Loch Aline, Morvern; Duart and Carsaig, I. of Mull.	Subzone of <i>Ammonites semicostatus</i> .
	Shelly limestones alternating with shales and crowded with fossils.	250	Enalosaurian remains; <i>Ammonites Bucklandi</i> , Sow.; <i>A. Conybeari</i> , Sow.; <i>A. kridon</i> , Hehl; <i>Nautilus striatus</i> , Sow. sp.; <i>Cardinia Listeri</i> , Sow. sp.; <i>Myaetes lasius</i> , Rein.; <i>Pholadomya glabra</i> , Ag.; <i>Astarte dentilabrum</i> , Eth.; <i>Pinna Hartmanni</i> , Goldf.; <i>Lima gigantea</i> , Sow.; <i>L. succinea</i> , Schloth. sp.; <i>L. pectinoides</i> , Sow. sp.; <i>Gryphaea arcuata</i> , Lamk.; <i>Pecten testorius</i> , Schloth.; <i>P.</i> , sp.; <i>Pentacrinus tuberculatus</i> , Mill.; <i>P. briareus</i> , Mill.	Applecross; Hallaig, I. of Raasay; Obe Breakish, Skye; Strath in Skye; Suddil and Mingary in Ardnurchan; Loch Alins, Morvern; Craignure, I. of Mull; Carsaig, I. of Mull.	Zone of <i>Ammonites Bucklandi</i> .
INTRA-LIAS.	Compact and oolitic limestones alternating with calcareous grits and conglomeratic sandstones, with occasional seams of coal and many carbonaceous markings.	400	<i>Ostrea irregularis</i> , Minst.; <i>Terpeunia arctis</i> , Quenst. sp.; <i>Pinna</i> , sp.; <i>Lima</i> , sp.; <i>Phascolionella</i> , sp.; <i>Univalves</i> ; <i>Rhynchonella</i> , sp.; and many fragmentary fossils; <i>Echinodermata</i> &c.; <i>Theosmitia Martini</i> , De From.; <i>Isaetra Murchisonae</i> , Wr.; Plant-remains, wood, &c.	Applecross; Hallaig, Raasay; Lussay and other parts of Strath in Skye; Suddil and Mingary in Ardnurchan; Ru-na-Gal, I. of Mull; Craignure, I. of Mull; South coast of Mull (?).	Zone of <i>Ammonites angulatus</i> and <i>A. planorbis</i> .
POIKILOLITE.	Soft reddish argillaceous and sandy beds, with some hard sandstones and conglomerates, occasional bands of concretionary siliceous limestones ("corstone") and gypsum.	200+	Casts of shells (<i>Cyrena</i> ?).	Greenstone Point, Grainard Bay; Ru-na-Leac, I. of Raasay; Strath; Skye; Suddil and Sron More, Ardnurchan; Innimore of Ardnurchan; Morvern.	Trias (Permian?).
	Red and variegated clays and marls, with occasional bands of corstone &c.	200+	No fossils found.	Greenstone Point &c.; Ru-na-Leac, I. of Raasay; Innimore of Ardnurchan; Ardnurchan Towers and shore of Loch Alue.	
	Coarse breccias and conglomerates alternating with sandstones, the rocks often having much calcareous material in their matrix.	500+	No fossils found.	Greenstone Point; Point of Ayre, I. of Raasay; Strath; Skye; Ru-Gour, Skye; Suddil and Sron More, Ardnurchan; Innimore of Ardnurchan; Craignure, I. of Mull.	

hereafter be proved to belong to the period between the Cretaceous and the Eocene, to the latter formation itself, or even to the Miocene.

With regard to the underlying beds no such doubt, fortunately, exists. We have clearly marine representatives of the Chalk with *Belemnitella mucronata*, Schloth., and of the Cenomanian or Upper Greensand; and the variable estuarine strata between these two marine series must be referred to the whole or to some part of the period represented in other areas by the Lower or Middle Chalk.

The existence of strata of littoral and estuarine origin, intercalated in the Upper-Cretaceous series in Bohemia and other parts of Eastern Europe, is a well-known fact. On the other hand, the recent researches carried on with so much perseverance by the United-States geologists in the western district of the North-American continent have rendered us familiar with thick formations of freshwater and terrestrial strata representing the same Upper-Cretaceous period, and also the interval between it and the Tertiary. Under these circumstances the discovery of these Scottish littoral and estuarine deposits is of very great interest—enabling us, as it does, to define a portion of the northern limits of the Cretaceous ocean. The bearing of these facts will be more fully discussed in the fourth and concluding part of this memoir.

VI. CONCLUSION.

Although, as I have before stated, it has been thought advisable to postpone the discussion of the numerous problems of interest which suggest themselves to the student of the remarkable relics of the Secondary rocks in the Scottish Highlands, until the fourth and concluding portion of this memoir is published—yet there are several questions which at the present time engage the minds of geologists upon which, as it appears to me, the facts and arguments of the present part of this memoir have an important bearing; and these it may not be undesirable to notice briefly at the present stage of the inquiry. Other and more general discussions will be allowed to stand over till such time as I have made the proposed comparison between the characters and modes of preservation of the beds under consideration and those of their equivalents in Ireland, England, Scandinavia, and other portions of the Continent.

I may briefly point out in the first place the great interest which attaches to the fact that there exists in the north-western part of the British archipelago a series of strata of Cretaceous age exhibiting evidence of the prevalence of estuarine alternating with marine conditions. The great and deserved amount of attention which is now directed to the similar beds, developed on such a grand scale in Western America, renders the discovery of the minute Scottish representatives of the period particularly important at the present time. It is tantalizing, however, to the British geologist to have to confess that, while he can demonstrate the undoubted fact of the existence of such strata, yet he is obliged to abandon almost all

hope of ever being able to collect from them (such is the imperfect manner of their exposure) the interesting remains of plant- and animal-life which would be so invaluable to him in enabling him to trace the ancestry of some of the Tertiary and recent types of life. The discussion of the question concerning the probable existence of land during the Cretaceous and later periods in the area now occupied by the Atlantic, and the more general problem of the possible permanence of the position of the great continents during vast periods of geological time, we reserve for a future occasion.

It is impossible to avoid noticing, in passing, the singular fact that in the north-western part of our archipelago both the Lower-Silurian and Upper-Cretaceous strata lose their ordinary characters, and show curious points of similarity to those displayed by the beds of equivalent age in the North-American continent.

The suggestion made some time ago, that the present Atlantic bed was in some sense "continuous with" the ancient Chalk strata of England, has been so thoroughly disposed of on palæontological and other grounds already, that it is perhaps scarcely necessary even to allude to it here. But if any trace of vitality still lingers in such a theory—and it is the nature of error to produce perennial crops—it is surely only necessary to point to the interesting fact, that in tracing the Chalk strata towards the Atlantic area they are found to assume estuarine characters and to afford the most unmistakable evidence of the close proximity of land in that direction, in order to set the question permanently at rest.

The conviction, however, that makes itself most strongly felt from a consideration of the details and arguments of the present part of this memoir, is that of the extreme danger to the geological inquirer of giving any important weight in his reasoning to *negative* evidence. The conclusions of the present paper, which will be strengthened in various ways by those which I hope to discuss on a future occasion, lend the strongest grounds of support to the view that over the greatest part of the British Islands, and far beyond that area, strata of various ages, from the Carboniferous to the Chalk inclusive, were once very widely spread, and have been removed by denudation during and since Mesozoic times. As a corollary from this proposition, which I believe that it will be possible to establish by the most unassailable arguments, we can scarcely help inferring that the reasonings so frequently indulged in concerning the former limits of areas of deposition in the past are of a very unsafe character, depending as they do in so many instances on such purely negative evidence as the absence of strata of a particular age from certain districts. We are too apt, perhaps, to forget how enormous has been the work of destruction of older strata in past times by denudation; and interesting as the new and isolated deposits of Carboniferous, Poikilitic, and Cretaceous strata (which I have now described for the first time as occurring in the Highlands of Scotland) are in themselves, yet their value and importance to the student of geology will be greatly enhanced if they be allowed to serve—as I believe they ought to do—as monuments of the enormous destruction effected by denuding

agencies during past geological epochs, and standing protests against the danger in geological speculations of drawing deductions from negative evidence. In palæontological geology the warning is perhaps scarcely necessary; for an accidental discovery of fossils has again and again occurred to produce a deep, timely, and salutary impression on the minds of rash theorists; and it is not perhaps too much to hope that an equal service will be rendered to the cultivators of physical geology by the discovery of these isolated and strangely preserved relics of vast formations in the Scottish Highlands.

NOTE on the FORAMINIFERA and other ORGANISMS in the CHALK of the HEBRIDES. By PROFESSOR T. RUPERT JONES, F.R.S., F.G.S.

[In the examination of specimens of the Cretaceous Rocks of the Hebrides I have been aided by Professors W. Kitchen Parker and T. Rupert Jones; and the latter has drawn up the following note on the sections which I submitted to him—J. W. J.]

No. O, 2. "Siliceous Chalk, Carsaig, W., Isle of Mull," and No. O, 3. "Siliceous Chalk, Beinn-y-Hattan," are specimens of *Inoceramus*-chalk—that is, made up to a great extent of prisms of *Inoceramus*-shell. In No. 3 some of these are pyritized. Foraminifera are abundantly present, constituting the matrix in which the prisms are imbedded. *Globigerina cretacea* is the most abundant; and others are present, such as *Dentalina*, *Virgulina*, *Bulimina*, *Planorbulina*.

No. O, 3*. "Siliceous 'Chalk,' Carsaig, E., Isle of Mull," and No. O, 4. "Flinty Chalk, Beinn-y-Hattan," are specimens of silicified *Globigerina*-chalk. The Foraminifera are much obscured, except here and there; and *Globigerina cretacea* is the only Foraminifer easily distinguished. *Inoceramus*-prisms and Sponge-spicules are obscurely indicated. Sand-grains (quartz) are present.

The occurrence of *Inoceramus*-prisms as important constituents of some kinds of Chalk has long been known. They form a large proportion of some strata of the Chalk at Charlton, near Woolwich, and elsewhere along the *Inoceramus*-zones.

Such prisms are figured by Prof. W. C. Williamson in his memoir "On some of the Microscopical Objects found in the mud of the Levant," &c. 1847, 'Manchester Lit. & Phil. Soc. Memoirs,' vol. viii. These prisms, figured in pl. iv. figs. 85 and 86, are described as such, and as being abundant in the "Chalk-detritus" (rotten Chalk-marl) of Charing, Kent, at pages 80, 81.

Prisms of *Inoceramus* are carefully described and figured in H. Eley's 'Geology in the Garden,' 8vo. 1859, p. 177, pl. i. fig. 1, &c., as abundant in some English Chalk-flints; and some are apparent in fig. 113, p. 210, of Heer's 'Primæval World of Switzerland,' 1876, illustrating a microscopic section of the glauconitic shales of the Swiss Gault with *Inoceramus concentricus*.

No. O, 4. Siliceous "Chalk, Gribun, Isle of Mull," is probably a *Globigerina*-chalk; but the Foraminifera are only obscurely indicated; so also are Sponge-spicules and *Inoceramus*-prisms.

No. O, 5. "Siliceous Chalk, Beinn-y-Hattan," is a *Globigerina*-chalk, composed of *Globigerina cretacea*, with *Textularia* and *Planorbulina*, and probably smaller organisms, Coccoliths, &c. Compare the hard Chalk from Larne (Antrim), which is very similar. Compare also the woodcuts, figs. 104-113, pp. 203-210, in the English edition of Heer's 'Primæval World of Switzerland,' 1876, for similar rock-material and organisms. These are more specially treated of in the 'Transact. Roy. Geol. Society of Ireland,' November 1872, where the Foraminiferal Limestone of Antrim is described.

No. O, 6. "Calcareous Grit, U.G., Carsaig, Mull." This siliceous and glauconitic grit, with calcareous cement, contains some pieces of (Molluscan?) shell and Foraminifera, such as *Textularia* and *Planorbulina*.

No. O, 8. "Micaceous glauconitic Sandstone, U. G. Loch Aline." This contains some obscure Sponge-spicules. Foraminifera, it is well known, are very abundant in the Chalk, constituting a very large proportion of its material. Mr. H. C. Sorby has estimated that in some specimens of chalk the shells and fragments of *Globigerina* form nearly 90 per cent. of the bulk. Coccoliths and Rhabdoliths, still smaller calcareous organisms, form the finer material of the Chalk. The small Entomostracan valves are sometimes in abundance; and prisms of *Inoceramus*-shells make up a large proportion of the Chalk in some places. Polycystina have not been noticed in the British Chalk. A very few Diatomaceæ were recorded by Ehrenberg from the Gravesend Chalk, but have not been otherwise observed. Foraminifers and Coccoliths are always present. The former belong to such kinds as at present live in the sea, from the littoral zone down to depths of 100 fathoms or more. Some of the same kinds, however, exist now at great oceanic depths; but the abyssal *Globigerina* of the present ocean grow much larger and coarser than those found in the Chalk.

The prepared specimens under notice from Carsaig, Beinn-y-Hattan, and Gribun fully illustrate the theory of the pseudomorphosis of the calcareous mud, or chalk-ooze, into silex, as established by Bischoff, and adopted by Duncan, Dowker, and others. See 'Proceed. Geol. Assoc.' vol. iv. 1876, p. 451, &c.

EXPLANATION OF PLATE XXXI.

In Fig. 1 an attempt has been made to show the general relations of the Volcanic rocks of the Western Isles, in illustration of the second portion of this memoir, which was specially devoted to the consideration of the ancient volcanoes of the district, both those of Newer Palæozoic and those of Tertiary age. In conformity with the plan adopted in the more detailed map of Mull, published with the second part of the memoir, the acid volcanic rocks of Tertiary age have been indicated by tints of red, the basic volcanic rocks of the same period by shades of blue, the darker colour in each case representing the intrusive masses, the paler the lavas, and the dotted surfaces tuffs and agglomerates. The fragments which have escaped denudation, of the great volcanoes of Mull, Ardnamurchan, Mull, and Skye respectively, can readily be seen from an inspection of this map, that of St. Kilda lying outside its limits. The little

group of the Shiant Isles probably represents the only remaining vestige of another great volcanic centre, which has been almost wholly removed by the denuding forces.

The same map is made to illustrate the distribution of those isolated patches of Secondary strata with which the present part of the memoir more particularly deals. As these exposures are not only of minute size, often, indeed, even when comprising series of beds hundreds or thousands of feet in thickness, covering no superficial area, but being displayed in absolutely vertical precipices under the almost everywhere superincumbent Tertiary volcanic rocks, the ordinary mode of representing strata of different ages on geological maps wholly fails us here. I have therefore coloured all the beds intervening between the Palæozoic and the Tertiary of one uniform conspicuous tint, and endeavoured by means of the lettering to show the ages of the various strata seen at different points. In order that they might be visible at all on a map of this small scale, however, the areas covered by the Secondary strata have had to be exaggerated in most cases.

Fig. 2 illustrates in a somewhat diagrammatic way the relations of the Secondary rocks to those older and younger than them respectively, especially the preservation of outlying patches of the Secondary strata, and the effects produced by the great post-Miocene fault of the Innimore of Ardtornish.

DISCUSSION.

Prof. RAMSAY remarked that the material placed before the Meeting was so vast in amount and so condensed in form, that it was impossible to grapple with all the author's statements. In general he had nothing to object to what the author had said; and probably if all the data had been laid before the Meeting, every one would agree to the statements contained in the paper. But, no doubt for want of time, the author had, it seemed to him, left some matters a little obscure. Did he mean to imply that the whole area of Scotland had once been overlain by Carboniferous strata? Prof. Ramsay quite agreed that a large portion of the British Islands was once so covered—three fourths of Ireland and a great part of England—but, he thought, not all Wales, nor all the Highlands of Scotland. His reasons were drawn from the history of the Palæozoic rocks. In the case of the Old Red Sandstone of Scotland, Mr. Godwin-Austen had proved this to have been deposited in fresh-water lakes. The masses of Old Red conglomerate in Scotland were sometimes of glacial origin, and were composed of the detritus of older Highland Silurian rocks. There must then have been lofty mountains for the origination of such glaciers; and there was high land during the Old-Red-Sandstone period. After the Old Red Sandstone we find great flat territories, thin beds of limestone, and of coal with underclays which partly showed estuarine conditions, and there must have been dry land in the neighbourhood. Evidence is still wanting to prove that the whole of the Highlands were covered by coal-beds. With regard to the faults described by the author, Prof. Ramsay thought such enormous downthrows as some of those mentioned to be improbable. He would remind his hearers that a fault may have great magnitude in one part, and die out to nothing within a distance of a few miles. All the mountains of Scotland were certainly not covered by Oolitic and Liassic strata.

With regard to the origin of the New Red Sandstone, he would ask whether the existing beds of rock-salt were consistent with deep-sea formation.

Prof. HUGHES could not follow the author altogether in his conclusions as to the age of the present surface of the district described. If the question was whether any part of the surface is now approximately the same as it was before the Pliocene period, he thought that much might be learned from a consideration of the plains of marine denudation which can be traced from districts in the south, where there is some evidence as to their age; and it would appear that some of these are Precretaceous, the margin of a lower plain being a shore-line along hills, the tops of which form part of a higher and probably older plain. He thought the greater part of the sculpturing should be referred to the period before the Pliocene.

Mr. CARRUTHERS stated that he had examined the exceedingly interesting vegetable remains brought by Prof. Judd, and that their nature left no doubt as to their truly belonging to the Coal-measures. They belong to the Upper and Middle series. To him this result had come quite unexpectedly. Could we also have fossils from the later estuarine rocks, much light might be thrown upon them. The Cretaceous fossils have Eocene affinities.

Mr. WHITAKER remarked that the Upper Estuarine beds were described as being clays and sands, and inquired what evidence there was of their being Cretaceous. May not some of them be Tertiary? The description of them is equally applicable to Tertiary and to Cretaceous deposits. He further inquired whether the lavas correspond with those on the north-east coasts of Ireland, and how they lie on the beds under them, and to how great an extent were the latter altered. How far do these Cretaceous beds answer to those at Aix-la-Chapelle?

Mr. WOODWARD said that he saw M. Devey's collection at Aix-la-Chapelle in April last, and that it contained many plants of Pliocene age. He thought that the leaves in the specimens on the table had a remarkably Eocene facies, and in this respect resembled those found in America. He inquired whether Prof. Judd had observed the lignite-beds in Antrim.

Dr. HICKS stated that in the district particularly studied by him he had found that great faults were very persistent through any distances.

Rev. J. F. BLAKE referred to the difference in character of the rocks described from those of England. The Carboniferous beds were formed in shallow water, near which there must have been high land; and this would have prevented the continuity of the several deposits. The estuarine character was repeated in the Oolitic series in Yorkshire, as also in the Lias. These deposits overspread large areas, but were not continuous, and could not have been formed in deep seas. So, too, with regard to the Chalk and Upper Greensand. He inquired whether Chalk is a shallow- or a deep-sea formation. He had always thought it was the latter; but Dr. Gwyn Jeffreys had

SECTION 10 MILES.



Mintern Bros lith.

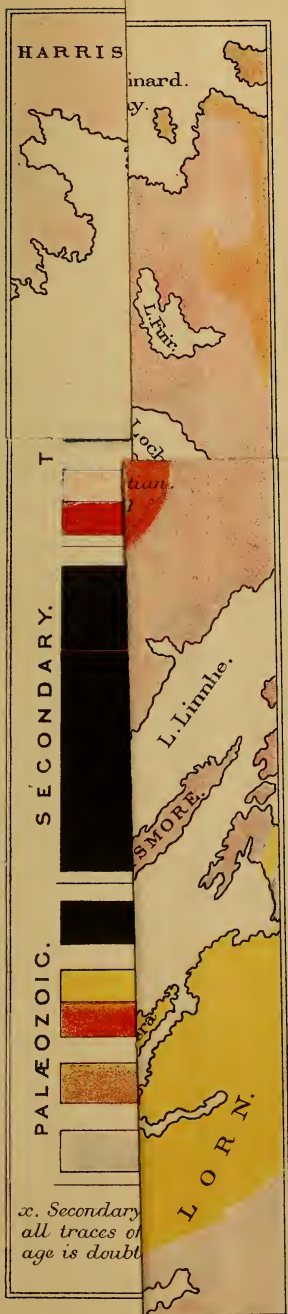
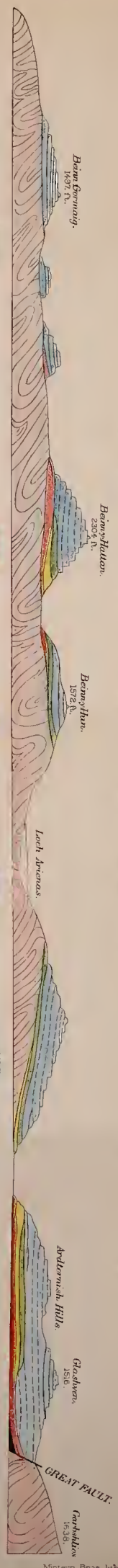
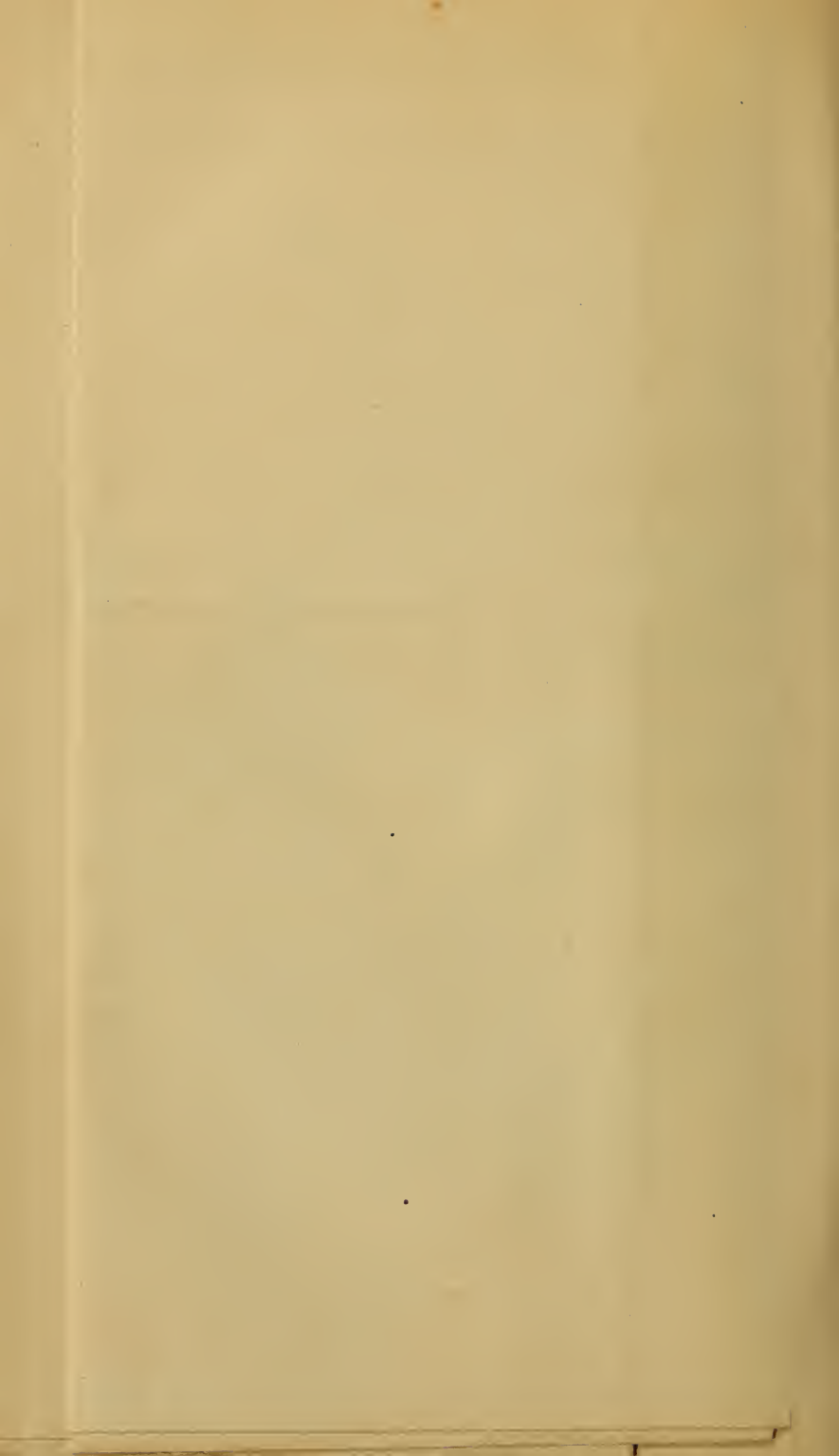


Fig. 2. GENERALIZED SECTION ACROSS THE DISTRICT OF MORVERN-ARGYLLSHIRE. LENGTH OF THE SECTION 10 MILES





lately declared its fossils to be those of a comparatively shallow sea. He also asked whether the Chalk in the district described was like that of the north of Ireland.

Mr. SOLLAS remarked that the outlines of land and sea were of first-rate interest to the geologist; and inquired whether a broad gulf of waters stretching across the Triassic plains of Cheshire and Lancashire, and over the North-east of Ireland and the North-west of Scotland, would not account for the facts without assuming a very general submergence of the British Isles. It seemed to him that to say from the present absence of Oolitic beds over large areas that such beds had never been was more philosophical than to deduce from it their former existence. In support of his opinions he indicated that in the south-west the Carboniferous land had a fringe of New Red Sandstone, and the Lower Lias had no Oolite over it. In the South-west there was evidence of shallow water close to a coast-line. It seemed to him that the absence of sedimentary beds proved that there had been no submergence. With regard to the Jurassic period, his notion was that all Wales, Devonshire, Cornwall, and the Pennine chain have been above water since the time of the Lower Lias.

The AUTHOR, in reply, said that Prof. Ramsay and Prof. Hughes seemed to think he ought to have approached his subject from their standpoint rather than from his own. All will agree that the Lias and the Chalk were not formed in lakes. Fragments of lavas occur throughout large areas; and under all of these the Secondary rocks are preserved. If they were not originally continuous across the existing gaps, we must assume that the sea went exactly to these limited spots, which was so unlikely as to be almost absurd. In reply to Mr. Whitaker, he said that the evidence was in favour of the Cretaceous nature of the beds, but the proof that they were not Eocene was not absolute. The basaltic lavas were Miocene, the others Eocene. The relations of lavas to the beds beneath them had been dealt with in a former paper. To Mr. Woodward he said that the Antrim lignites are not Cretaceous, but Tertiary; to Mr. Blake, that all the beds are not estuarine, but there are immense thicknesses of marine deposits with fossils; and to Mr. Sollas, that he preferred at present dealing with the ascertained facts, reserving the treatment of the theoretical questions involved for a future paper.